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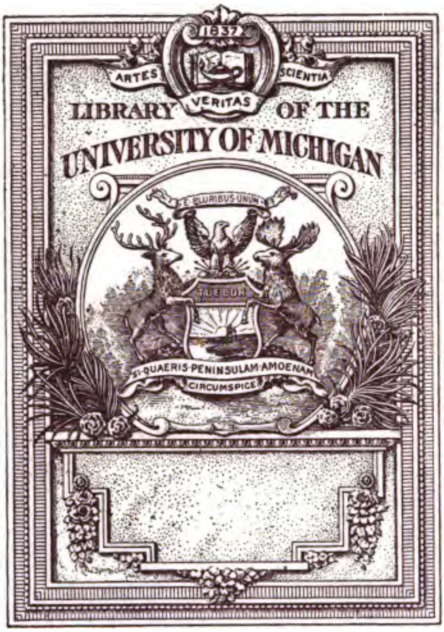

THE GIFT OF
State Geologist

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GEOLOGICAL SURVEY OF NEW JERSEY

ANNUAL REPORT

OF THE

STATE GEOLOGIST

For the Year 1906

TRENTON, N. J.
MacCrellish & Quigley, State Printers.
1907

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The Geological Survey of New Jersey.

BOARD OF MANAGERS.

His Excellency Edward C. Stokes, Governor and *ex-officio* President of the Board, ...Trenton.

Members at Large.

Herbert M. Lloyd, ...	Montclair, ...	1907
Harrison Van Duyne, ...	Newark, ...	1907
S. Bayard Dod, ...	Orange, ...	1908*
John C. Smock, ...	Trenton, ...	1908
Thomas W. Synnott, ...	Wenonah, ...	1909
Alfred A. Woodhull, ...	Princeton, ...	1909
Emmor Roberts, ...	Moorestown, ...	1910
David E. Titsworth, ...	Plainfield, ...	1911
George G. Tennant, ...	Jersey City, ...	1911

Congressional Districts.

I.	Frederick R. Brace, ...	Blackwood, ...	1911
II.	P. Kennedy Reeves, ...	Bridgeton, ...	1907
III.	M. D. Valentine, ...	Woodbridge, ...	1909
IV.	Washington A. Roebling, ...	Trenton, ...	1908
V.	Frederick A. Canfield, ...	Dover, ...	1910
VI.	George W. Wheeler, ...	Hackensack, ...	1911
VII.	Wendell P. Garrison, ...	Orange, ...	1907†
VIII.	Joseph L. Munn, ...	East Orange, ...	1909
IX.	Joseph D. Bedle, ...	Jersey City, ...	1908
X.	Aaron S. Baldwin, ...	Hoboken, ...	1910

State Geologist,

Henry B. Kümmel.

* Died April 19th, 1907.
† Died February 27th, 1907.

TRENTON, N. J., November 30, 1906.

To His Excellency Edward C. Stokes, Governor of the State of New Jersey, and ex-officio President of the Board of Managers of the Geological Survey:

SIR—I have the honor to submit my Administrative Report upon the work of the Geological Survey for the year 1906. This will be followed by papers dealing with the Glass Sands, the Copper Deposits and other subjects, these with the Administrative Report comprising the Annual Report of the State Geologist. It has not been possible to complete these papers so as to submit them at this time, but the work on all of them is far advanced. I recommend that advance copies of the Administrative Report be printed for use of the Legislature and the printing of the whole report be deferred until these papers can be completed. In this way the result of the investigations of this department may be placed most quickly before the citizens of the State.

Yours respectfully,

HENRY B. KÜMMEL,

State Geologist.

ADMINISTRATIVE REPORT.

Administration, Organization, Publications, Distribution, Library, Collections, Correspondence.— Topography, Field Work, Office Work.—Geology, Peat, Building Stones, Trap Rock and Copper Ores, Sands, Iron Ores, Mineral Waters, Artesian Wells, Pleistocene Stratigraphy, Paleozoic Stratigraphy, Paleontology, Paleobotany.—Co-operation with the U. S. Geological Survey.—St. Louis Exposition Medals.

Administrative Report.

HENRY B. KÜMMEL, STATE GEOLOGIST.

A summary of the work of the Geological Survey during the fiscal year ending October 31, 1906, is set forth in the following pages of the Administrative Report, which, when published in its final form, will be accompanied by several papers giving in detail the results of the work along particular lines.

ADMINISTRATION.

Organization.—In March, Mr. David E. Titsworth, of Plainfield, was appointed as a member at large on the Board of Managers to succeed Senator Ernest R. Ackerman, whose term had expired and who declined re-appointment. Messrs. Tennant, Brace and Wheeler, whose terms also expired, were re-appointed for five years.

During the year the following persons were employed upon the Survey, the majority of them at a per diem compensation:

Henry B. Kümmel, State Geologist.
R. B. Gage, Chemist.
Laura Lee, Clerk.
Howard M. Poland, Office assistant.

Rollin D. Salisbury, Surface Geology.
G. N. Knapp, Surface Geology and Artesian Wells.
Stuart Weller, Paleontology.
E. W. Berry, Paleobotany.
J. Volney Lewis, Trap Rocks.
C. W. Parmelee, Peat Testing.
W. E. McCourt, Building Stones.

C. C. Vermeule, Topographer.
P. D. Staats, Assistant Topographer.
W. A. Coriell, Draughtsman.
L. M. Young, Topographic assistant.
Clarence Bruen, Topographic assistant.
C. V. Coriell, Topographic assistant.
J. B. McBride, Topographic assistant.

Alma B. Roump, Stenographer.
Anabelle Lesser, Stenographer.
C. B. Hardenberg, Draughtsman.
E. J. Davis, Clerk.

Publications.—For various causes, in large part beyond the control of the Survey, the publication of the Annual Report of the State Geologist for 1905 (pp. 338 + X, plates XXX, figures in text 21) was delayed and the completed volume was not ready for distribution until the middle of October. Advance copies, however, of the administrative report and of two scientific papers were printed early in the year and were ready for the use of the Legislature. The completed volume contained the following papers:

Administrative Report,	24 pp.
Changes Along the New Jersey Coast—Lewis M. Haupt, C. E.,	70 pp.
A Brief Sketch of Fossil Plants—Edward W. Berry,	38 pp.
The Flora of the Cliffwood Clays—Edward W. Berry,	38 pp.
The Chemical Composition of the White Crystalline Limestones of Sussex and Warren Counties—Henry B. Kümmel, with analyses by R. B. Gage (with map),	16 pp.
Lake Passaic Considered as a Storage Reservoir—C. C. Vermeule (with map),	30 pp.
A Report on the Peat Deposits of Northern New Jersey—C. W. Parmelee and W. E. McCourt (with map),	86 pp.
The Mining Industry—Henry B. Kümmel,	12 pp.

Three new Atlas sheets, Pluckemin, Somerville and New Brunswick, on the large scale (2,000 feet per inch) were published in May, and at once placed on sale. Twenty-four sheets on this scale are now completed and are being distributed as

rapidly as orders are received. One hundred and two sheets on this scale are necessary to cover the entire State, but the sheets already published cover the more populous centers. There is practically no demand for sheets of this character covering the strictly agricultural and woodland areas, for which the maps of the earlier series on the smaller scale amply suffice. It is doubtful therefore whether it will be advisable to issue in the near future many more sheets on the larger scale.

One sheet, No. 21, on the one-inch per mile scale, was reissued in August, after extensive revision of the cultural features. This sheet, covering northern Warren and western Sussex counties, replaces the old Sheet No. 1, although it does not cover exactly the same limits.

Distribution.—The demand for the maps and reports issued by the Survey is, to a certain extent, an index of the degree to which the work of the department commends itself to the people. This is particularly the case with respect to the maps which are not distributed gratuitously but are sold at 25 cents per sheet. Judged by this test the work is approved, since the map sales during 1906 numbered 4,581 sheets as against 3,187 for 1905 and 2,236 for 1904. It is true that the number of different sheets on sale has increased from 37 in 1904 to 43 in 1906, but the average number of copies sold per sheet was 60 in 1904, 80 in 1905 and 107 in 1906. There were 653 separate orders, making an average of 7 sheets to each order. During the past year the sales of both the one-inch maps and the large-scale sheets have increased about 50 per cent., and about 700 more copies of the latter were sold than of the former. The unexpected increase in the demand for these maps during the last two years has exhausted the editions of many of the older sheets, and necessitated the printing of new editions. The time seemed opportune for extensive revision, so as to bring the new editions down to date. This has been done, although in some instances it has delayed the publication of the maps and increased very considerably the proportion of Survey funds needed for this work, but it has been necessary in order to maintain the high standard of excellence for our maps established in previous years.

The total number of reports sent out during the year is set forth in the following table, which shows a considerable falling off over the last two years. The reason for this is found in the fact that three reports—two annuals and Volume VI, the Clay Report—were issued in 1904 and 1905. Not only were these three reports distributed to a long mailing list, but their distribution, particularly that of Volume VI, stimulated a demand for the previous reports. The Annual for 1905 was sent out so late in 1906 that the demand for back reports, which is usually aroused by a new volume, has not yet been felt.

Below is shown in tabular form the distribution of reports and maps for 1905 and 1906:

	1905.		*1906.*	
Annual Report for 1905,			3,237	copies.
" " " 1904,	3,279	copies	147	"
" " " 1903,	165	"	72	"
" " " 1902,	71	"	43	"
" " " 1901,	60	"	42	"
" " " 1900,	77	"	67	"
" Reports between 1883-1899,	775	"	570	"
Final Reports, Vol. II,	238	"	99	"
" " Vol. III,	151	"	81	"
" " Vol. IV,	136	"	85	"
" " Vol. V,	175	"	89	"
" " Vol. VI,	985	"	177	"
Other Reports,	126	"	107	"
Total Reports,	6,238	"	4,716	"
Map sheets—				
Scale 1 inch per mile—19 sheets,	1,245		1,974	
Scale 2,000 feet per inch—24 sheets,	1,942		2,607	
Total map sheets,	3,187		4,581	

Library.—The accessions to the library of the Survey during the year were 55 bound volumes, 119 unbound volumes, 109 pamphlets, 88 maps. The bulk of these were obtained by exchange.

Collections.—The geological collections of the Survey have not been materially increased during the year, but much has been done towards making the material on hand more accessible for

reference. The mineral and rock specimens have been numbered, and the labels entered in a permanent accession book. Index cards have also been prepared for many of the specimens. Some work has been done upon the paleontological material, but it will be some time before all collections are properly classified. When the work is completed there will be a list of all specimens arranged numerically in a book, and a card index arranged by subjects and localities. A permanent label number in paint has been placed on each specimen, and there is no chance of the specimen becoming valueless by reason of its label being lost. Mr. Poland has performed this work under my direction as he has had time from other duties.

There are still on hand four of the mineral collections prepared for the use of schools of the State which are available for distribution to any school, upon payment of $25.00 to cover the cost of preparation, labelling and packing.

Correspondence.—Many letters are received containing inquiries of various sorts. These have a wide range, varying from a request for the elevation above sea level of some point in the State, or the area of some lake, questions which can be readily answered by reference to the publications of the Survey, to more complicated requests for advice in reference to underground water supplies, the occurrence and chemical composition of glass sands, peat, pure limestone and a host of other subjects. In many instances the inquiry can be answered by sending one of the printed reports; in other cases it is necessary to spend considerable time in looking up the necessary data, comparing the evidence, and writing a letter in reply. It is the policy of the Survey to reply to all communications as fully as possible and to furnish the desired information whenever possible, in the belief that such a course best brings our work into close touch with the people. No charge is made for information of this character. Not a few of the inquiries come from other States, and, in some cases at least, the information furnished is believed to have resulted in the establishment of new industries here.

Occasionally the Survey is in receipt of letters asking for information regarding New Jersey mining propositions which are being "promoted" on the market. It is a matter of extreme

difficulty to reply to these in such a way as to be absolutely fair to all parties. It is no part of the work of the Survey to offer advice to prospective investors (either for or against a proposition), but it is a proper function to set forth through its reports, and in response to inquiries, geological facts known and of record which bear upon the case. Ordinarily, it is believed that our duty to the investing public is done when such a reply has been made to a direct inquiry.

It seems necessary, however, to call attention here to the recent prospectus of a company promoting a zinc-mining proposition near Franklin Furnace, adjoining the well-known mines of the New Jersey Zinc Company, for the reason that the work of the State Geologist is cited in such a way as to make it appear that this department endorses the claims set forth in the circular. The Geological Survey most emphatically does not do this. There are no facts in its possession which warrant the claim that zinc ore in commercial quantities occurs anywhere in the State except in the two famous ore-bodies at Franklin Furnace and Stirling Hill, respectively. Thousands of dollars have been spent in recent years in diamond drilling on neighboring properties in the vicinity of these ore-bodies with negative results so far as this department knows. In all future prospecting by this means, it should be clearly recognized by those whose money is invested, that exploration with a diamond drill is very expensive, costing several dollars per foot, that the expenditure of $20,000 may be necessary to test properly a single hole, and that the chances of locating a workable body of zinc ore by one or two holes put down in the crystalline limestone even in the most favorable spot are very remote.

Maps published in the Annual Reports of the State Geologist for 1890 and for 1905 show that the property of this company is not underlain entirely by the white limestone, as is claimed, but in large part by the blue limestone which is highly magnesian in character and utterly valueless for the purposes of Portland cement manufacture. White crystalline limestone, containing very little magnesia, does, however, occur on their property but much less extensively than the other.

The prospectus quotes parts of a report on this property written in 1903 by Mr. Frank L. Nason, who is referred to as if he

were a member of the State Survey when he made the report, whereas he severed his connection with the Survey in 1890. This abridged report misrepresents facts and tends to mislead, but in justice to Mr. Nason, who was an active and painstaking worker on the Survey for a number of years, it should be stated that the report as written by him and the report as published in the prospectus, lead to very different conclusions.

Editorial.—In addition to preparing parts of the Annual Report for 1905, the manuscript of the balance was read and edited by the State Geologist, and the entire report read both in galley and page proof.

TOPOGRAPHIC WORK.

Mr. C. C. Vermeule has continued to direct the topographic work with P. D. Staats, W. A. Coriell, L. M. Young, Clarence Bruen, C. V. Coriell and J. B. McBride as assistants for varying periods.

Field Work.—Early in the year the revision of Sheet 21 was commenced, and owing to the mildness of the weather it was possible to continue the field work even during January and February, covering 270 square miles. Some field work was found to be necessary in connection with the proof sheets of the Pluckemin, Somerville, and New Brunswick sheets. Owing to alterations at the County Buildings at Somerville, two bench marks of the Survey were in danger of destruction. Temporary bench marks were established, and on the completion of the new County Buildings they will be transferred and made permanent. It was not possible last year to complete the surveys in reference to the proposed lake in the upper Passaic Valley, described at length in the Report for 1905, so that considerable field work was necessary during the early part of this year. Delay in publishing the Report for 1905, however, made it possible to include the results of these studies in that report.

Office Work.—Drawings for photolithographing the Pluckemin, Somerville and New Brunswick sheets were completed, and the changes on Sheet 21 were transcribed and copy made ready for the engraver. The work of preparing a borough and town-

ship map to be printed in color was completed and copy sent to the lithographer. Drawings were made of the Lake Passaic map. In addition to this, the proof of seven maps was read and corrected.

The growing popularity of the Survey maps, as evidenced by the increased sales, has already been alluded to. A new State Map, on a scale of 5 miles to 1 inch, and corrected so as to show the boundaries of all boroughs, townships, cities and counties, as they existed after the adjournment of the last Legislature, has been prepared and will be published soon. It will be printed in colors to make the political boundaries more prominent. The demand for it will probably be large. It will be Sheet No. 38, and will be sold at the regular price of 25 cents.

GEOLOGIC INVESTIGATIONS.

Peat.—The laboratory determinations necessary to complete the report upon the peat deposits kept Mr. Parmelee busy during the winter and spring. His conclusions were published as part of the Annual Report for 1905, it being deemed better to delay the completion of that volume slightly, so as to ensure prompt publication of these results.

Building Stones.—Mr. McCourt, in continuation of the experiments commenced a year ago, has made a few more tests upon the building stones of the State, to determine their fire-resisting qualities. The discussion of his experiments, with illustrations showing the effect of sharp changes of temperature upon his specimens, will be published as a paper to accompany this report.

Trap Rock and Copper Studies.—Mr. J. Volney Lewis has continued his investigations of the petrography of the trap rocks, and the questions which bear upon the origin of the copper ores so commonly found in the shales in close proximity to them. The rocks of the Newark formation, including the traps, were discussed in some detail in the Annual Reports for 1896 and 1897, but certain phases of the subject were not touched upon at all, and others are shown by further study to be susceptible of a different interpretation. In the last few years there has been

a marked change in the opinion of geologists regarding the origin of extensive formations of shale and sandstone, formerly accepted without question as of estuarine or lacustrine origin, but now believed more probably to be fluviatile deposits. For some time the writer has felt that his discussion of this subject in the Annual Repart for 1897 was inadequate, and should be revised, and for this reason he is pleased to direct attention to the alternative view outlined by Mr. Lewis in his report.

The correlation with each other of the various trap masses as developed by Mr. Lewis is highly suggestive. Although it can not be claimed that it rests upon so firm a basis of ascertained facts, as do many of the other conclusions regarding these rocks, nevertheless there is nothing inherently improbable in his conclusions, and much can be said in their favor. They can be accepted, therefore, as a good working hypothesis to be held until definitely disproved.

The explanation given by the writer in the Annual Report for 1897, for the double crest of Second Mountain with the beds of shale in the valley, was never wholly satisfactory and was offered with considerable hesitation, and a full comprehension of the inherent difficulties. The alternative hypothesis proposed by Mr. Lewis seems less beset with difficulties and it should probably replace the earlier view.

Regarding the origin of the copper ores, the view put forward by Mr. Lewis that they are deposits from ascending magmatic waters expelled from the great intrusive mass, whose separated portions now outcrop as the Palisades, Rocky Hill, Sourland Mountain, etc., varies distinctly from the view suggested by Dr. W. H. Weed,* respecting the ores under the trap ridge of the First Watchung Mountain. Owing to this difference of opinion, the facts set forth by Mr. Lewis in support of his hypothesis are of more than ordinary interest.

Another feature of interest in his report will be found in the tests of the resisting qualities of the trap as determined by a series of experiments carried out by the co-operation of the Director of the Office of Public Roads, Department of Agriculture, at

* Annual Report of the State Geologist for 1902, p. 137.

Washington, D. C. Inasmuch as the trap rocks are used very extensively for road metal, these tests of their wearing qualities should prove of value when considered with regard to the results already shown by actual usage. Mr. Lewis' discussion of the petrographic features of the trap rocks will be considered in a subsequent report.

Sands.—A brief paper has been prepared upon the glass sands of the State. Chemical analyses of the New Jersey sands show that they contain more iron than do the Pennsylvania sands with which they come in competition, with the result that the latter bring much better prices per ton at the glass factories.

The methods of washing the sands practiced at the pits remove the fine clay and silt which remain suspended in the water, and also the grains and pebbles too large to pass a 30-mesh sieve. Mineralogical examination of the samples of washed glass sands collected by the Survey shows that practically all the iron and titanium shown by chemical analyses is contained in small grains of rutile, ilmenite, sphene and leucoxene (?). As Mr. Gage points out in his report, if the iron-bearing minerals can be removed by improved methods of washing, by magnetic separation, sieving, or any method which in its practical operation is not too expensive, a grade of glass sand equal to or even superior to the best Pennsylvania sand can readily be obtained. When the difference in price between the Pennsylvania and the New Jersey sand as at present marketed is considered, the importance of this point to local glass-sand miners is apparent.

Iron Ores.—During the year, Dr. W. S. Bayley, in the time available from his other work, has continued his compilation of data regarding the iron mines of the State. It is expected that it will be completed during the present year and be published early in 1908. In this connection a detailed map of the Hibernia mines is being prepared on a large scale. The report will be accompanied by other maps, both of the surface and of the underground workings of various mines.

Mineral Waters.—Late in the year Mr. Gage visited the mineral springs of the State, the waters of which are placed on the market and have a more or less extended table use. Samples were taken and mineral analyses will be made in the near future.

The use of bottled spring water for drinking is increasing rapidly, as the surface supplies become open to suspicion through contamination by sewage.

Artesian Wells.—The underground water supplies of the State have long been a subject for study by the Survey. In many of the Annual Reports, notably those from 1890 to 1903, records of many artesian and other deep wells were published and some attempts made to correlate water horizons. In 1904, Mr. G. N. Knapp began the work of revising these records and correlating the many samples of borings which the Survey had obtained. This work was at first undertaken in co-operation with the Hydrographic Division of the U. S. Geological Survey, and the expense was defrayed by them, in consideration of the initial work done by the State Survey in collecting the data. For various reasons Mr. Knapp has been delayed in the completion of the work, and the U. S. Survey was compelled to give up further participation in it. Since August 1st the work has been carried on at the expense of the State Survey, and the report will be completed by the end of December.

It is proper here to state that the U. S. Geological Survey in ceasing to co-operate further in this investigation freely waived all claims to any part of the results already reached.

Stratigraphy. Pleistocene.—The interpretation and mapping of the surface sands and gravels of southern New Jersey have engaged the attention of the State Survey under Mr. Salisbury and his assistants portions of each year since 1892. Similar deposits in States further south were studied by other workers, and results were reached by them which did not harmonize with those put forth by this department. When the southern interpretation was carried northward and applied to deposits on the west side of the Delaware, and then extended into New Jersey, the differences in view were emphasized and the necessity for a modification in some direction was apparent. This was the more necessary since the U. S. Geological Survey is publishing a geological atlas of the whole country, and is working in co-operation with the New Jersey Survey as well as with some other State surveys in their respective States.

In June a field conference was held in New Jersey; in which Messrs. C. W. Hayes and Benjamin L. Miller, of the U. S. Geological Survey, and R. D. Salisbury and G. N. Knapp, of the New Jersey Survey, together with the State Geologist, took part. The deposits on both sides of the Delaware river were examined with maps in hand which represented the diverse views. The result of the conference was the acceptance of the interpretation and the mapping urged by the workers on the New Jersey Survey, and the decision to bring the Pennsylvania work into harmony with it. Some changes in the details of our mapping, in part because of clerical errors in transcribing the maps, were suggested and agreed to, but the subdivisions advocated and the interpretation put upon the deposits by the New Jersey Survey were accepted as correct by Mr. Hayes for the National Survey. This decision removes one of the causes of the long delay in publishing the geologic atlases of the southern part of the State.

Upon the termination of this conference, Mr. Knapp took up and by the end of July completed his maps and manuscript upon these formations. The final report will now be prepared for publication by Mr. Salisbury, and will be a companion volume to his Report upon the Glacial Geology, which was published in 1902 as Volume V.

Stratigraphy. Paleozoic.—The structural relations of the limestones and shales of Warren county present some interesting features which were the subject of careful examination during a few days in July by the State Geologist. The normal Paleozoic succession in the Kittatinny valley is as follows, from the top downward:

Hudson shales and slates, thickness great.

Trenton limestones (essentially non-magnesian), 100-200 feet.

Kittatinny limestone (mostly magnesian), thickness probably about 3,000 feet.

Hardyston quartzite, 20-150 feet.

This succession can usually be traced in making a cross-section from the crystalline Highlands to the Kittatinny Mountain, which is composed of the Shawangunk conglomerate (more frequently called Oneida conglomerate, but recently determined by the New York Survey to be Salina in age). In the vicinity of Hope,

Johnsonburg and the northern end of Jenny Jump Mountain, however, the structure is very complicated and the relations of the rocks can be determined with difficulty. Areas of the Kittatinny limestone of varying size occur surrounded entirely by the Hudson slate, while the Trenton limestone, which should occur between them, is entirely absent. That these are not simply eroded anticlinal folds showing the older rocks in the center surrounded by younger beds is shown both by the absence of the Trenton formation and by the inclination of the strata which do not possess the anticlinal structure. That the region has been greatly faulted is evident even upon cursory examination, but data to determine the exact nature and position of the fault planes, as well as the direction and amount of thrust, are not easy to find. It seems demonstrable, however, that in the folding which occurred in this region the limestone was thrust horizontally over the shale from southeast to northwest for a considerable distance. Later in the folding the thrust plane itself became somewhat folded, being depressed in troughs and rising in broad gentle arches. Subsequent erosion has removed hundreds of feet of sediment. Where the thrust plane was depressed so as to be still below the limit to which erosion has now progressed, that is below the present surface, the overthrust beds of limestone are found upon the slate. Where the thrust plane was slightly arched the limestones have been removed, and the present surface is in the shales below the thrust.

This explanation makes clear also the presence of several small areas of crystalline rocks, the occurrence of which within the limestone and slate areas far removed from the great mass of gneisses and granites, is not readily explained on other hypotheses. They are not intrusives in the sedimentary rocks, nor are they normal exposures of the underlying crystallines revealed by deep erosion. On the contrary, like the limestone areas above referred to, they are remnants of the basal rocks which in the folding were thrust horizontally over and upon the much later sediments.

Paleontology.—Dr. Weller has almost completed his studies of the fossils found in the sands, clays and marls of the Cretaceous strata, and the report will soon be ready for publication. It will

add much to our knowledge of the life of this period, and will be a valuable contribution to the Paleontology of New Jersey. Owing to its purely technical character, only a small edition will be printed, and its distribution will be limited.

Paleobotany.—A small allotment was made Mr. E. W. Berry in connection with like sums from the Maryland Survey and the National Survey to enable him to continue his studies of the fossil plants of the Coastal Plain, the money contributed by this department being spent only in New Jersey.

Co-operation with the U. S. Geological Survey.—As already indicated, a field conference has been held with representatives of the U. S. Geological Survey, as provided by the agreement made in 1904*, at which the interpretation of the non-glacial Pleistocene deposits of the southern counties, urged by Messrs. Salisbury and Knapp, of the State Survey, were accepted for use in the geologic atlas. This, of course, involved the rejection of the opposing view, and will necessitate the re-mapping by the U. S. geologists of the same formations on the Pennsylvania side of the Delaware River to bring them into accord with the New Jersey work. It is hoped that, as soon as this is done, the maps of this region can be issued without further delay.

In June the manuscript descriptive of the Paleozoic sediments on the Franklin Furnace quadrangle was prepared and sent to Washington. The State's share of this work has now been completed. The manuscript of three other quadrangles is in various stages of preparation, but it is difficult to say when the completed maps will be issued.

Awards at the Louisiana Purchase Exposition.—During the year the Geological Survey received the medals indicative of the awards made to it for its display at the St. Louis Exposition in 1904. A grand prize was received for the maps and models; four gold medals for the exhibits of clays, rocks and minerals, fossil restorations and collective exhibit respectively, and a silver medal for a museum petrographic microscope. The medals are all of bronze metal, but the various grades are distinguished by their shape and by slight differences in design.

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*Annual Report of the State Geologist for 1904, p. 15.

PART I.

The Fire-Resisting Qualities of Some New Jersey Building Stones.

By W. E. McCOURT.

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INTRODUCTION.

In order to determine the durability of a building stone a number of tests are performed on it. Certain tests are, in certain cases, more important than others, though all are desirable in order to get at the relative merits of building stones. There is one test which has often been neglected, and this is the effect of extreme heat. This is of much importance in some cases, especially when the stone is to be used in a location where a conflagration is apt to occur.

Accordingly, a number of samples of New Jersey stones were collected by the writer during the summers of 1904 and 1905, under the direction of the State Geologist, and these were tested in the Geological Laboratory of Cornell University, in connection with work for an advanced degree. The object of this

investigation was to ascertain the relative ability of the various stones to withstand extreme heat, and to determine, as far as possible, the criteria which control the refractive ability.

The writer wishes to express his appreciation of the courtesies extended to him by the various laborers, superintendents and owners at the quarries visited. Thanks are due to many, but special mention is due Mr. W. J. Ledger, of the S. B. Twinning Co., Mr. Merriman, resident engineer at the Boonton Dam, Mr. George Sweezy, of the Federal Hill Granite Co. and Mr. Herbert K. Salmon, of the North Jersey Stone Co. To Dr. A. C. Gill, of Cornell University, acknowledgment is due for help in the petrographic descriptions of the samples, and to Dr. Heinrich Ries, of Cornell University, for general criticism of the entire work. Most of the photographs for this paper were taken by Mr. G. F. Morgan, of Ithaca.

EARLIER INVESTIGATIONS.

Investigations of the refractoriness of building stones are comparatively few. Cutting[1] was the first to perform any extensive tests and from his results he came to the conclusion that the various stones for building purposes withstand extreme heat in the following order: Marble, limestone, sandstone, and granite, but all were injured to some extent.

Buckley[2] carried on a series of tests on Wisconsin and Missouri building stones, and came to the conclusion that a stone with a simple mineralogical composition, and a uniform texture has the greatest capacity to withstand high heat. According to him, limestones, up to the point of calcination, acted best of all the stones, but beyond that point they flaked off at the corners. The granites all cracked, though in varying degrees, the coarser grained ones suffering the greatest injury, while the sandstone showed little outward evidence of damage, but most of them could be crumbled in the hand.

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[1] Weekly Underwriter, XXIII, 42, 1880. Ibid XXII, 257, 287, 304, 1880.

[2] Wis. Geol. & Nat. Hist. Sur. Bull. IV, 73 & 385, 1898. Mo. Bur. of Geol. & Mines, II, 2nd series 50, 1904.

The consensus of opinion seems to be that granites are the least refractory of the building stones. The limestones and marble calcine and flake off at a high heat, while some of the sandstones stand up well, and others are reduced to sand.

OBSERVATIONS IN BURNED BUILDINGS.

The literature of the effect of fires on the various kinds of stone was studied to see if any facts might be deduced, but we cannot safely draw any definite conclusions, since the actual conditions in a fire are varied, and there have never been any detailed or accurate observations made at the time of the conflagration. However, it is of interest to note that in an intense fire all stones are injured to some extent, especially where the stonework is thin or exposed. Until accurate observations of the different conditions of exposure, amount of heat, etc., in a conflagration are made, we cannot safely draw any conclusions from this source as to the relative refractoriness of the different building stones.

METHOD OF MAKING FIRE TESTS.

In the tests to be described 3-inch cubes were used. All other investigators have employed smaller cubes, but these do not give so accurate results as those of a larger dimension. When a larger cube is heated, the heat penetrates only a slight distance into the body, while the interior may remain comparatively cold. Upon cooling there are set up differential stresses which would not be caused in a small sample of the stone. Tests have been made on larger and smaller cubes of the same kind of stone, and invariably the small pieces stood the heat much better than the larger cube. Naturally, then, the large cube should always be used, as this approximates more closely conditions which prevail in buildings.

As far as possible six tests were made on the stone from each locality. Four of these tests were made in a Seger gas-furnace, which allowed the cube to be gradually and evenly heated. In

the cover of the furnace an opening was cut large enough to admit the specimen, to which a wire had been fastened in order to facilitate handling. Two flame tests were carried on, and for these an ordinary blast lamp was made use of.

In the furnace tests one sample was heated at a time. After the cube had been placed in the furnace the heat, measured by a thermo-electric pyrometer, was applied gradually for half an hour until a temperature of 550° C. (1022°F) was reached. This degree of heat was maintained for half an hour, and at the end of that time the sample was removed from the furnace and allowed to cool in the air. The second cube was heated like the first, but this was suddenly cooled by the application of a strong stream of water. The third and fourth samples were heated to 850° C. (1562°), kept at that temperature for half an hour and then cooled, one slowly and the other suddenly, as the tests at 550° C.

In the first flame test the cube was so placed as to be enveloped on three sides by a steady but not strong gas blast. The flame was allowed to play on the cube for 10 minutes, then the sample was allowed to cool for five minutes, at the end of which time the flame was again applied for 10 minutes and the cube was again allowed to cool. The second flame test was carried on somewhat similarly to the first test, but in this case a strong stream of water was applied, along with the flame, for five minutes after the cube has been subjected to the flame alone for 10 minutes. The water was turned off and the flame allowed to act on the cube for another five minutes, after which, for five minutes more, the flame and water together acted on the sample.

SAMPLES TESTED.

Samples tested were obtained from the following localities:

LOCALITY.	COUNTY.	COMPANY.	Plate Reference.
GRANITES AND GNEISSES.			
German Valley, 1 mile northwest,	Morris,	Lyman Kice,	I.
Cranberry Lake, 2 miles south,	Sussex,	North Jersey Stone Co.,	II.
Cranberry Lake,	Sussex,	Panther Hill Granite Co.,	II.
Montville, 1 mile north,	Morris,	Jersey City Water Supply Co.,	III.
Pompton Junction,	Passaic,	Federal Hill Granite Co.,	IV.
Dover,	Morris,	Thomas Fanning,	V.
Mt. Arlington,	Morris,	North Jersey Stone Co.,	VI.
Waterloo,	Morris,	North Jersey Stone Co.,	VII.
Hibernia, 3 miles northwest,	Morris,		VIII.
Morristown, 1 mile west,	Morris,	P. Lubey,	IX.
DIABASES.			
Plainfield, 1 mile west,	Somerset,	F. W. Wilson & Co.,	X.
Lambertville,	Hunterdon,	B. M. & J. S. Shanley,	XI.
SANDSTONES.			
Wilburtha,	Mercer,	De Graves Bros.,	XII.
Stockton,	Hunterdon,	S. B. Twinning Co.,	XIII.
Raven Rock,	Hunterdon,	Stockton Stone Co.,	XIV.
Martinsville, ½ mile south,	Somerset,	W. E. Bartle,	XV.
Pleasantdale,	Essex,	F. W. Shrump,	XVI.
Avondale,	Essex,	Belleville Quarry and Stone Co.,	XVII.
Avondale,	Essex,	Belleville Quarry and Stone Co.,	XVII.
North Arlington,	Hudson,	Geo. Bayliss,	XVIII.
Closter, 2 miles east,	Bergen,	J. Gamble & Son,	XIX.
LIMESTONES.			
Franklin Furnace,	Sussex,	Nicol Limestone Co.,	XX.
Newton,	Sussex,	O'Donnel & McManiman,	XXI.
Phillipsburg,	Warren,		XXII.
ARGILLITE ROCK.			
Princeton, 1 mile north,	Mercer,	Margerum Bros.,	XXIII.

RESULTS OF THE TESTS.

General Summary.—The crystallines, at a temperature of 550° C. (1022° F.) were not greatly affected, and the cracks which were developed were but slight. The gneisses, as a rule, cracked parallel to the banding, and as a general thing it is fairly safe

to say that a gneiss will be more damaged than a crystalline rock of the same texture and similar mineralogical composition without the banding. The sample of clay rock from Princeton acted badly. Clay rocks usually suffer much damage in a fire. Well known examples of this are seen in the splintering and shivering into fragments of the roofing slates and those used on staircases. The sandstones, as a whole, resisted well at the lower temperature, while the limestones seem to have suffered the least injury of all the stones tested at 550°.

The degree of heat which is reached in a conflagration undoubtedly exceeds 550° C., but outside of the severe part of the fire there would be buildings subjected to a temperature of 550° or thereabouts. The stones in such buildings would probably suffer very little injury. Limestones would act best, provided the point of calcination had not been reached. Sandstones would follow limestones in their ability to resist the damage from the heating. To be sure, this series of tests has shown that some of these New Jersey samples cracked, but the cracks are slight, and in most cases parallel to the planes of bedding. This damage would not materially affect the stability of the structure if the stones had been properly set on their beds. Fine-grained crystallines would follow sandstones, and last would come the coarser crystallines.

When we approach a heat equal to 850° C. (1562° F.) we approximate fairly well the probable degree of heat which is reached in a conflagration. In this series of experiments the crystallines, as a class, acted badly, though some samples gave better results. In the case of the igneous rocks the main factor controlling the refractoriness seems to be the texture. The finer-grained varieties act much better than the coarser ones. In the stones of the fine texture the cracks are small and quite regular, with a tendency to split off the corners, whereas in the stones ot coarser texture the cracks are irregular and open, and in some cases they were so bad as to cause the cube to crumble. The gneisses would suffer great injury and the amount of damage would be largely controlled by variations in texture and the amount and style of banding. Those stones in which there are seams of coarser material will crack considerably more than the

even-grained varieties, and the much banded gneiss will tend to split more readily, especially in a direction parallel to the banding.

Naturally the sandstones vary somewhat in their ability to withstand the effect of this extreme heat. Here the controlling factors seemed to be texture, composition, kind of cementing material and manner of cementation. The coarser-grained stones and those made up of various mineral constituents suffered worse than the finer-grained and more simple ones. It is to be inferred that a compact stone will suffer less than one in which there are a number of pore spaces. The greater the percentage of porosity, in general, the greater will be the damage. A very porous stone will be reduced to sand, while a dense one will behave quite creditably. A coarse stone will crack irregularly, while a finer-grained one will split more regularly and in most cases in a direction parallel to the lamination planes. A sandstone which has a cement of limonite or one in which there is a large percentage of clay will crack more readily than one in which silica or calcite bind the grains together, for the reason that the water is driven off from the clay and limonite, and as a consequence greater stresses are set up in the stone.

The limestones, at the higher temperature, because of the fact that the calcination point has been reached, flaked and in some cases went to pieces. A pure limestone suffered greater injury than the impure or dolomitic samples.

The results of the flame tests cannot be considered as indicative of the probable effect of a fire on the body of the stone in a structure, but, more correctly, may be considered as a probable indication of the effect on thin edges of stone, such as lintels, pillars, projecting corners, carving, etc. All the classes were injured in these tests. The degree of heat reached in these experiments did not exceed 700° C., so it is safe to say that all thin edges of stone would suffer in a conflagration, possibly so much so as to need repairing. The tendency seemed to have been for the cubes to split off in shells around the point of greatest attack. This concentric peeling is seen in nature in the exfoliation of granite or other rocks in regions where there are decided changes in temperature, especially between the day and night. It has also been observed in buildings which were

located in the burned districts of Paterson, Baltimore and San Francisco.

At a temperature, then, which is probable in a fire, the finer-grained and more compact the stone and the simpler in mineral composition the better will it be able to resist the damaging effect of extreme heat. The sudden cooling by a stream of water will cause more injury than the slow cooling. Many of the samples assumed a brownish tinge upon being heated, due to a change of the iron present in the stone, from a ferrous to a ferric state.

If the temperature does not exceed 550° C. all the building stones tested in this series will be little damaged, and they will resist injury in this order: limestone, sandstone, fine-grained crystallines, coarse-grained crystallines and clay rocks, the first being most resistant. If, however, the temperature be higher, all thin edges of stone work will suffer and the various stones tested in this set of experiments will resist in the following order, the first on the list offering the greatest resistance to injury; fine-grained compact sandstones, medium-grained dense sandstone, fine-textured granites, fine-grained gneisses, impure limestone, loose sandstone, coarse granite, coarse gneiss, clay rocks and pure limestone.

Granites and Gneisses.—But two samples remained apparently unaffected after 550° C. slow-cooling test, those from Montville and Waterloo (Plates III. and VII.) The others suffered some, though very slight, injury. The cubes from Pompton Junction and Morristown show only a number of minute cracks on the polished surfaces, which do not seem to have weakened the stones. The small crack in the Dover sample (Plate V.) is in the coarser texture. All the other cubes tested at this temperature developed some small cracks. Those from German Valley, Montville, Mt. Arlington and Morristown were changed in color to a brown tinge, due, probably to a change in the condition of the iron present in the stones. Usually, on fast cooling, a stone is more damaged than on slow cooling at the same temperature, but the two samples of gneiss from Cranberry Lake remained uninjured upon fast cooling, but were cracked somewhat in the slow-cooling test. Upon fast cooling, at 550° C. all

the other cubes suffered some injury, though it was still slight; the only severe case being the stone from Morristown, which had one bad crack extending around three sides of the cube.

Upon slow cooling, at 850° C. we found that the damage was still worse, though in some cases yet comparatively slight. The sample of gneiss from Pompton Junction, which was the coarsest stone tested, was badly and irregularly cracked and lost some of its particles in the test (Plate IV). The Mt. Arlington and Waterloo samples developed a number of small cracks, and the latter looked as if a blow would crumble it. The German Valley cube developed one open crack almost around the sample and the stone from Montville showed a number of small cracks. The cubes from Dover and Morristown were badly damaged, but in these cases the cracks were largely in the coarser seams. In the latter sample there was also a larger piece broken off one edge. Upon fast cooling at 850° C. we found that here, as in most cases in the 550° C. tests, the fast-cooled cubes were more injured than the slow-cooled ones, and all at this temperature in a fire, if cooled quickly by a stream of water would probably suffer great injury. The cube from Pompton Junction crumbled, those from German Valley and Montville were badly and irregularly cracked and lost some small spalls. Here, again, the cracks in those stones of varying textures seem to be more or less limited to the coarser seams.

All the samples were injured by the action of the flame, though in varying degrees. The cube from Montville (Plate III.) was broken into two pieces; the Mt. Arlington sample was broken into a number of pieces (Plate VI.) and all the others, as can be seen by reference to the plates, lost pieces from the corners, and in all cases show some cracks, the Pompton Junction samples being badly cracked. Under the combined action of the flame and water, the Morristown sample lost a smaller piece from the attacked corner than in the flame test, but it was considerably more cracked. All the cubes suffered, both by losing pieces from the corners and by being cracked. The stones from German Valley, Dover, Mt. Arlington and Waterloo look as if a blow would easily crumble them.

Judging from these tests, most of these stones would stand a low heat quite well, especially if not cooled by a stream of water. At a higher heat, however, they would probably act badly, and if exposed in corners, on window sills and the like, they would suffer great injury. The finer-grained stones seem to stand up better than the coarser ones and in those stones in which there is a variation of texture the cracking seems to be greater and more severe, especially in the coarser seams. The cracking in the gneiss has a tendency to follow the banding, though this is not a definite rule. A polished surface will show minute cracks, not noticeable on an unpolished face.

Diabase.—Two samples of diabase were tested, a fine-grained variety from Plainfield and a medium-grained one from Lambertville; but we cannot compare these two, inasmuch as the Plainfield stone contains a number of calcite spherules, which very materially affected the behavior of the stone in the tests. It would be interesting to test a sample of this finer-grained stone containing no calcite. Then we could determine more definitely the factors controlling the refractoriness, for the composition, both mineralogical and chemical, would be practically the same and we would have only the difference in texture as a variable factor.

In the 550° C. slow-cooling test the sample from Lambertville developed one slight crack around two sides. In the fast-cooling test, at this same temperature, the cracking was a trifle more marked, extending around three sides. The cube from Plainfield took on a brown tinge and developed several cracks.

At 850° C. the Lambertville stone was little affected, showing only several very small cracks, but the cube from Plainfield was broken into numerous small pieces, due, probably, to the calcite giving off carbon dioxide in changing to CaO, and thus exerting a breaking pressure. In the rapidly cooled cube a similar result was brought about, while the sample from Lambertville developed several cracks, one of which was opened and showed on three sides.

Under the flame the Plainfield stone spalled somewhat on the exposed surfaces and developed one crack, while the Lambertville cube lost a one-inch piece from the corner and was slightly

cracked. Under the flame and water test the damage was, in both cases, greater, larger pieces being broken from the corners and more cracks developed.

Sandstones.—Among the sandstones there is much variation in the capacity of the different samples to resist the effect of extreme heat. Some seemed little affected, while others were badly injured.

Some of the cubes, Pleasantdale (Plate XVI), Avondale (Plate XVII), North Arlington (Plate XVIII), and Closter (Plate XIX), remained uninjured on slow cooling, after having been heated to 550° C. On fast cooling the Pleasantdale and North Arlington samples developed slight cracks, while the cube from Closter still remained unaffected. A coarse variety of stone from Avondale (Plate XVII), was uninjured by the sudden cooling. The stones from Martinsville and North Arlington took on a brownish tinge because of the change in the condition of the iron present. All the other samples showed some injury, though only slight, both on slow and sudden cooling, and in most all cases the cracks in the samples were parallel to the planes of lamination.

In the 850° C. tests all of the stones were injured, though in varying degrees. The most pronounced cracks, in all cases, are along the bedding planes, though many of the stones also show transverse cracks. The samples from Stockton (Plate XIII) and Martinsville (Plate XV) were quite badly injured on slow cooling, and more so on fast cooling. The cubes from Wilburtha (Plate XII), Avondale (Plate XVII) and Closter (Plate XIX) suffered much injury on rapid cooling. The sample from Pleasantdale (Plate XVI) came through the flame test with only slight cracks, and the Martinsville (Plate XV) and Closter (Plate XIX) cubes had but small pieces broken off from the corners. The others were much impaired.

Under the action of the flame and water, the stone from Closter (Plate XIX) remained unchanged, but all the others had large pieces broken from the corners, and except those from Raven Rock (Plate XIV) and Martinsville (Plate XV), showed many cracks in addition.

Limestones.—In both of the 550° C. tests all of the cubes remained apparently unchanged, except the sample from Phillipsburg, which developed several small cracks when cooled quickly.

In the 850° C. series all the cubes were injured to a greater or less extent. The Franklin Furnace stone was badly injured, so much so as to make it worthless at this temperature (Plate XX). The cube from Phillipsburg developed some bad cracks, especially along the veins of calcite, while the Newton sample stood the test fairly well. The Franklin Furnace stone was thoroughly calcined on the outside, while the two other stones were little calcined, due to the impurity of the samples.

In the flame tests all lost pieces from the attacked corner, besides showing several cracks in each case, the Newton cube suffering the greatest injury by being broken into several pieces. Under the action of the flame and water the injury was still greater, all of the samples being so broken as to render them useless.

We see, then, that the limestones will stand up very well at 550° C.; at 850° C. the coarser and more pure seem to have suffered the greater injury, and the sample ribbed with veins of calcite was injured more than the one with no such veins. All acted quite badly under the flame, and more so under the flame and water.

Argillite.—This sample is an extremely fine-grained rock from Princeton, much like a shale, but which contains an abundance of calcareous material.

Upon slow cooling, after having been heated to 550° C the cube was split along the bedding, besides showing other parallel cracks (Plate XXIII). Upon fast cooling some transverse cracks were developed, but most of the bad cracks extend parallel to the lamination planes.

The flame test developed one slight crack along the bed and around three sides, while the flame and water together broke a small piece off the upper edge, besides cracking the sample around three sides along the bed.

Plates and Detailed Description of Tests.

PLATE I.

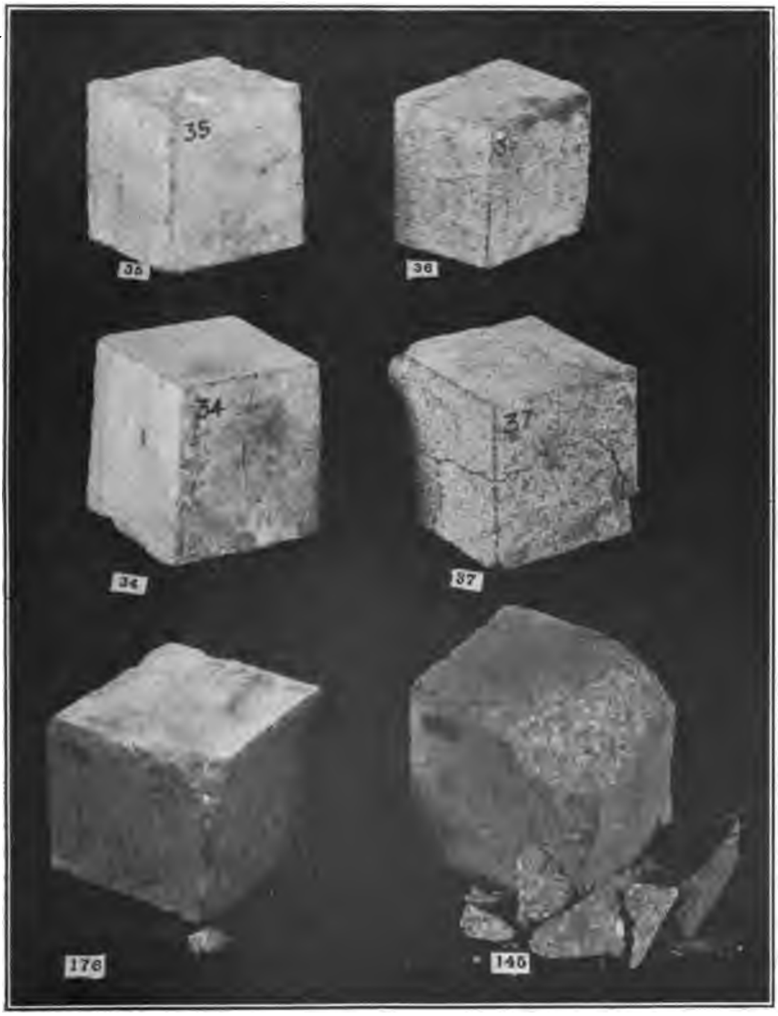
SYENITE, FROM QUARRY OF LYMAN KICE, GERMAN VALLEY, MORRIS COUNTY.

This is a medium-grained greenish stone used for building purposes. It is made up largely of feldspar, with much green augite and some quartz. Under the microscope, the feldspar, which is very fresh, appears to be mostly microperthite and some plagioclase. The green augite and quartz make up the remainder, with the exception of a few good crystals of zircon, some rounded apatites and a few magnetite grains.

Fire Tests.[1] In all of the tests this sample suffered some injury, quite noticeable in the 850° C. tests, especially in the rapidly cooled tube, where the stone was very badly cracked. Under the action of the flame the injury was slight as compared to that of the flame and water test. In most cases the stone was discolored.

No. 35.	550° slow-cooling test.	No. 36.	550° fast-cooling test.
No. 34.	850° slow-cooling test.	No. 37.	850° fast-cooling test.
No. 176.	Flame test.	No. 145.	Flame and water test.

[1] In all tests, the temperatures cited are Centigrade not Fahrenheit.



Syenite. German Valley, Morris County.

PLATE II.

Nos. 67, 68, 177, 146. GNEISS FROM NORTH JERSEY STONE COMPANY'S QUARRY, CRANBERRY LAKE, SUSSEX COUNTY.

This is a light-grey stone made up of light feldspar and quartz, with numerous small garnets scattered through the body. The quartz is less abundant than the feldspar, of which an acid plagioclase is the principal species, although orthoclase and some microcline microperthite are also present. The microscope also revealed the presence of some scales of biotite, which, in places had been bleached and in others had been altered to epidote. Some garnets and one zircon crystal were also noted in the section.

Fire Tests. At 550° C. the stone acted well, the fast-cooled cube being apparently uninjured, while the slowly cooled sample showed but one small crack on one side. No samples were tested at 850° C. In the flame test the stone lost some small pieces and in the flame and water test it was damaged to a slightly greater extent.

No. 67. 550° slow-cooling test.	No. 68. 550° fast-cooling test.
No. 177. Flame test.	No. 146. Flame and water test.

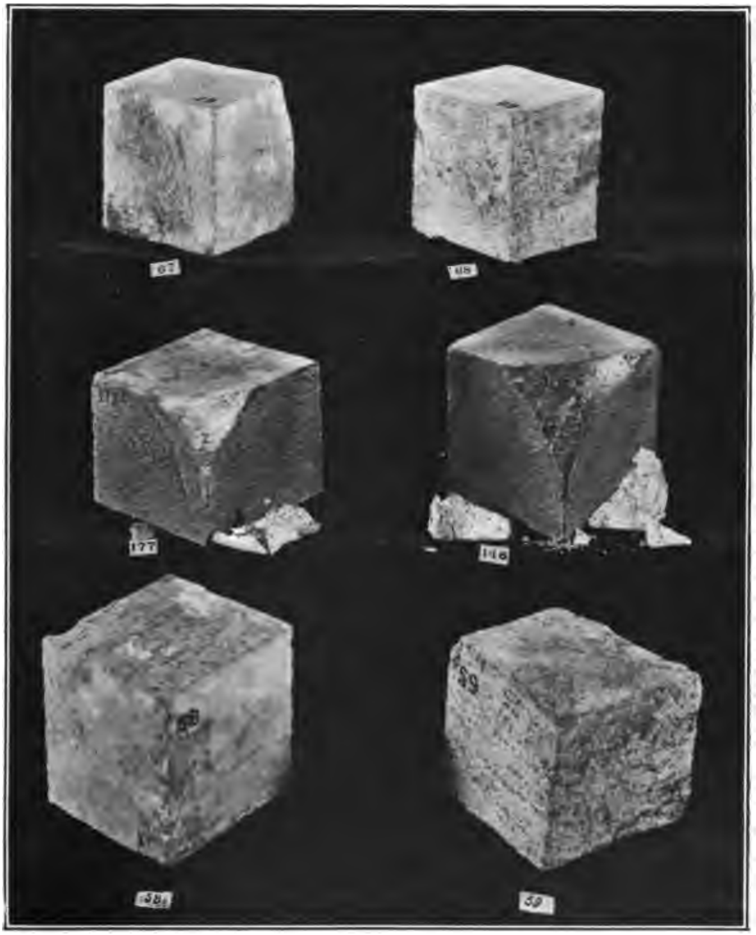
Nos. 58, 59. GNEISS FROM PANTHER HILL GRANITE COMPANY'S QUARRY, CRANBERRY LAKE, SUSSEX COUNTY.

The stone from this quarry, which is used as a building stone, has a grey color and shows a good gneissic structure. Feldspar is more abundant than quartz, and the darker minerals evident in the hand specimen are hornblende and augite. The microscope showed the presence of much sphene. The green augite is more

abundant than the green hornblende, to which it has altered in places. The quartz is less abundant than the feldspar, which is mostly an intergrowth of very acid plagioclase, some microcline and microcline microperthite. Rounded apatites are not rare and one scale of muscovite was noted in the section.

Fire Tests. Only two tests were made on this stone, both at 550° C., in which the samples seem to have been little damaged. Upon slow cooling the cube showed one small crack at one corner, but not bad enough to seriously injure it. This stone, like many of the others, took on a brownish tinge.

No. 58. 550° slow-cooling test. No. 59. 550° fast-cooling test.



Gneisses. Cranberry Lake, Sussex County.

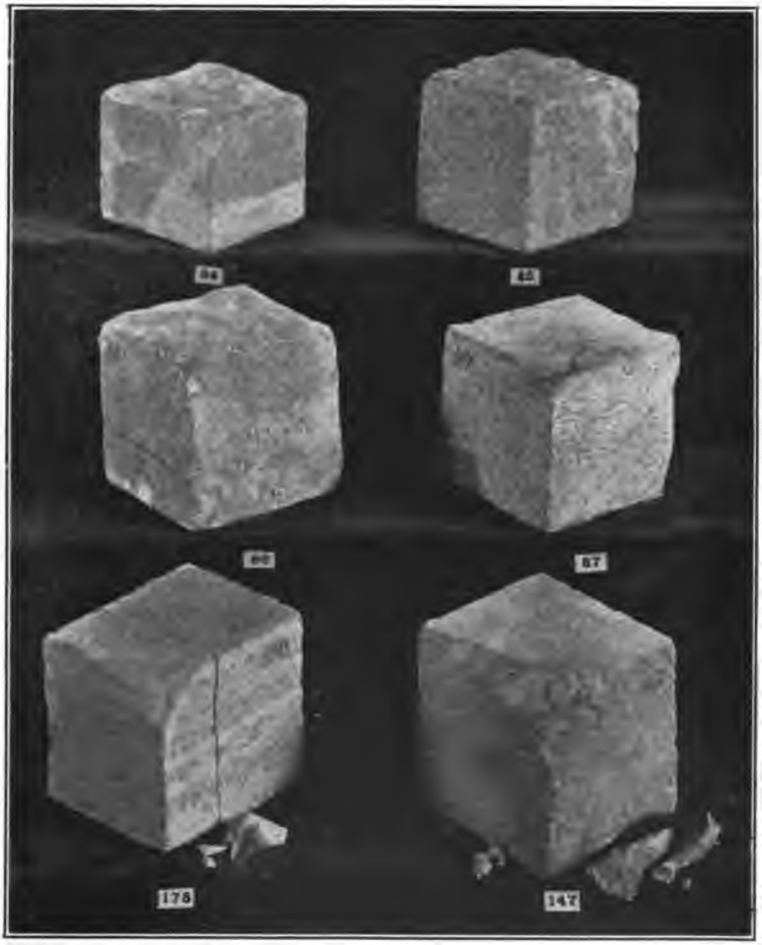
Plate III.

Gneiss from the Jersey City Water Supply Company's Quarry, Montville, Morris County.

The stone from this locality is very variable, both in texture and mineral composition. The coarser-grained kind is made up entirely of quartz and feldspar and some of the crystals are over one-half inch in size. The samples which were tested are medium grained and of a dark-grey color, composed of feldspar, quartz and some biotite. The stone was quarried only for use in the construction of the Boonton Dam.

Fire Tests. Upon slow cooling at 550° C. the cube remained intact, and but a few small cracks were developed on rapid cooling. All these samples were changed in color to the brown, so characteristic of many of the stones. At 850° C. the samples were irregularly cracked, the fast-cooled cube slightly more so than the slowly cooled one. For the most part the cracks are parallel to the gneissic banding. Under the flame the cube split into two large pieces, besides losing a small piece from the exposed corner, and while it did not break into two pieces under the action of the flame and water, it was considerably cracked and lost several small pieces.

No. 84. 550° slow-cooling test.
No. 85. 550° fast-cooling test.
No. 86. 850° slow-cooling test.
No. 87. 850° fast-cooling test.
No. 178. Flame test.
No. 147. Flame and water test.



Gneiss. Montville, Morris County.

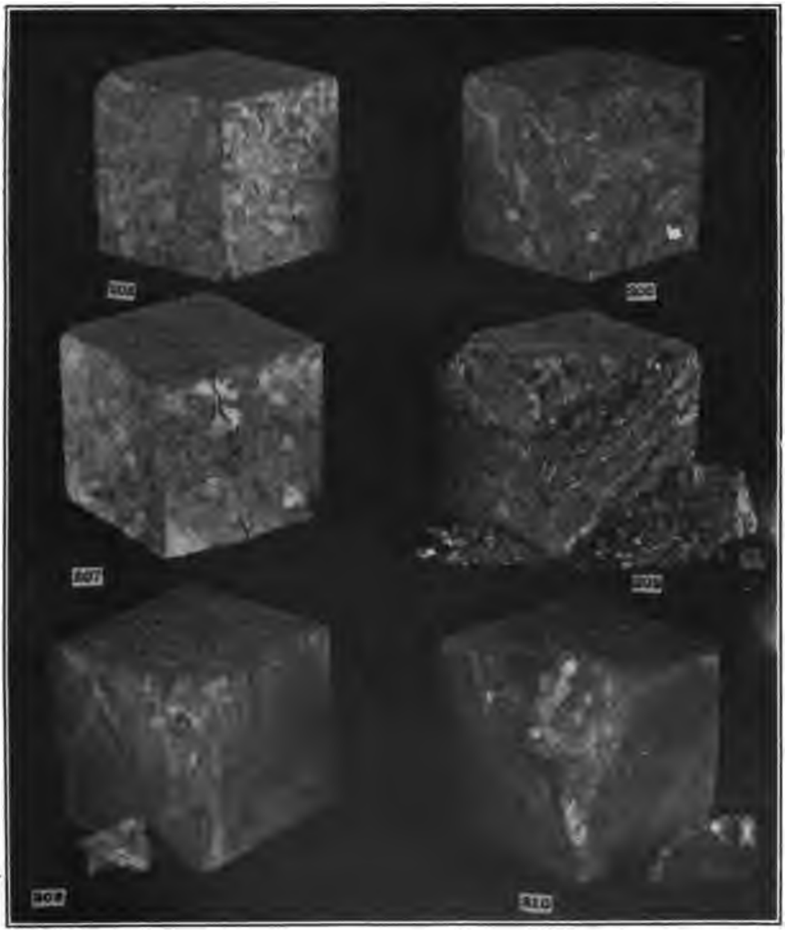
Plate IV.

Granite-Gneiss from Federal Hill Granite Company's Quarry, Pompton Junction, Passaic County.

This is a pinkish stone which is used for general building purposes. It is very coarse-grained, some of the crystals having a size of over three-quarters of an inch; pink feldspar, smoky quartz and green hornblende are easily distinguished in the hand specimen. In some places the hornblende has weathered, thus giving a green stain to the stone.

Fire Tests. This coarse-grained stone was little damaged in the 550° C. tests. The slowly cooled cube developed some minute cracks on the polished face, more especially in the feldspars, which is due, probably, to the cleaveage. The fast-cooled sample shows several small, irregular cracks around the grains, not enough, however, to materially weaken the stone. In the 850° C. experiments the samples acted badly, the slowly cooled cube was considerably cracked and the fast-cooled one was so damaged as to cause the stone to crumble. This is probably due to the extreme coarseness of the grain. In the two flame tests the samples lost small pieces from the exposed corners.

No. 205. 550° slow-cooling test.
No. 206. 550° fast-cooling test.
No. 207. 850° slow-cooling test.
No. 208 850° fast-cooling test.
No. 209. Flame test.
No. 210. Flame and water test.



Granitic Gneiss. Pompton Junction, Passaic County.

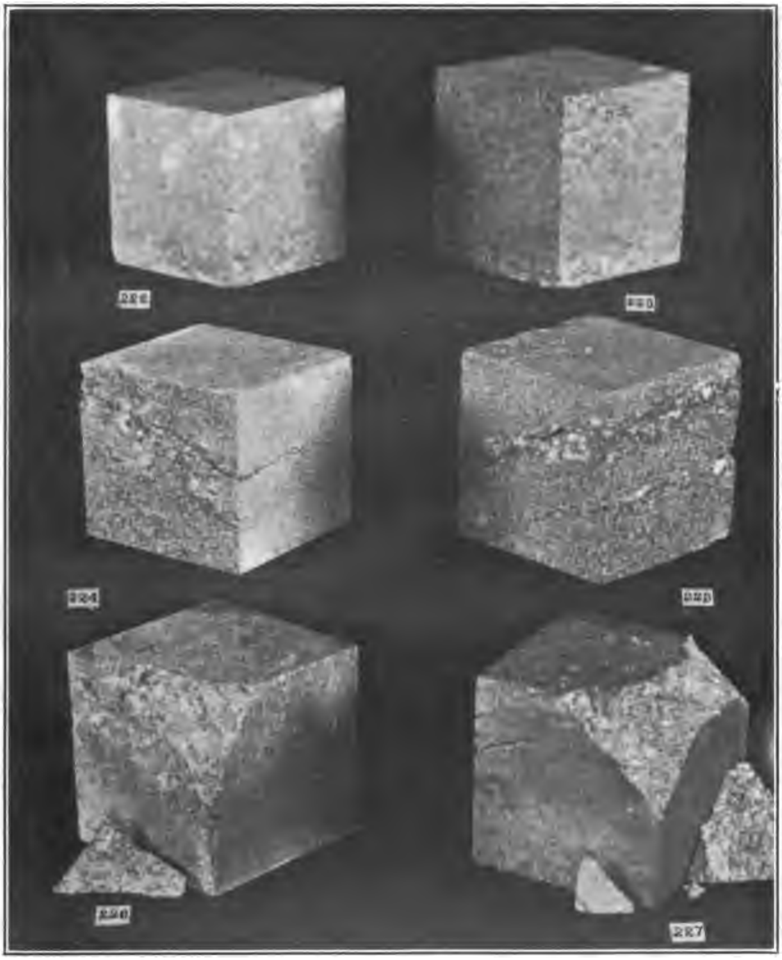
PLATE V.

GNEISS FROM THOMAS FANNING'S QUARRY, DOVER, MORRIS COUNTY.

This is a greenish stone used for structural work, of uneven, though prevailingly medium, texture and of irregular composition. However, in the samples tested, quartz, feldspar and hornblende could be distinguished.

Fire Tests. This stone assumed the brown tinge. In the tests at the lower temperature both of the cubes developed a small crack in the coarser seam, but these cracks are so slight that they would not probably affect the stability of the stone. In the higher temperature tests the cracking was so great as to injure the stones considerably, the cracks extending almost around the cubes. Here, too, the cracks seem to be confined to the coarser seams so frequent in the stone. The flame tests broke the pieces from the corners and developed some cracks, one very bad one in the cube which was subjected to the flame and water.

No. 222. 550° slow-cooling test.
No. 223. 550° fast-cooling test.
No. 224. 850° slow-cooling test.
No. 225. 850° fast-cooling test.
No. 226. Flame test.
No. 227. Flame and water test.



Gneiss. Dover, Morris County.

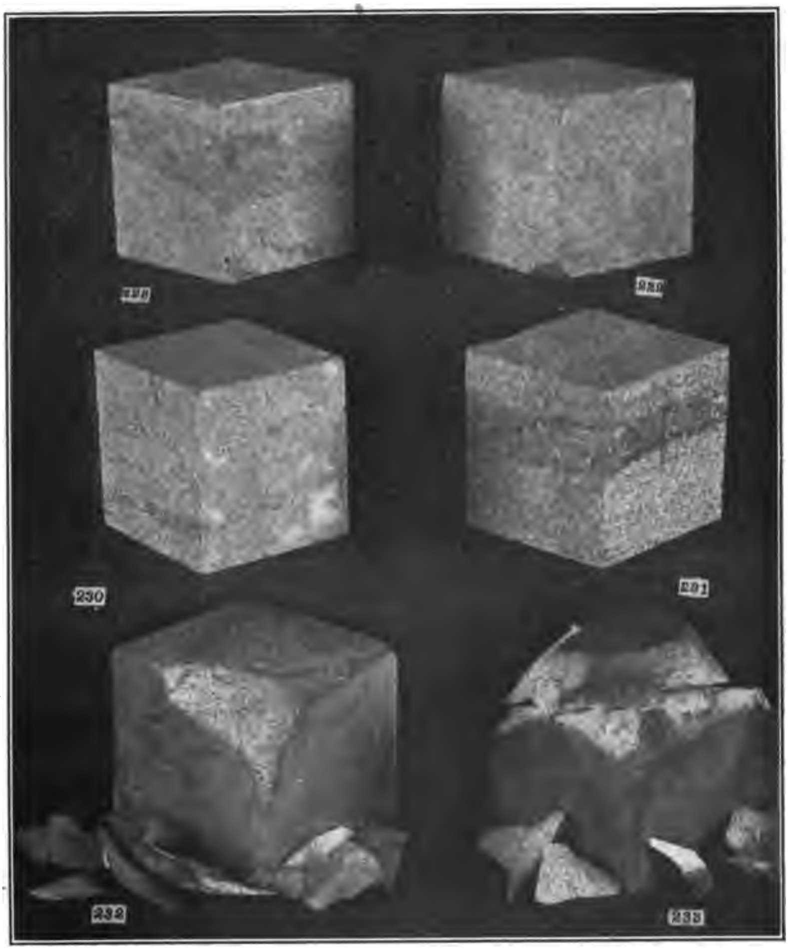
Plate VI.

Gneiss from the North Jersey Stone Company's Quarry, Mt. Arlington, Morris County.

This building stone has a gray color and is uneven in texture. The finer-grained parts seem to be made up of quartz, feldspar and black hornblende. The coarser seams give to the stone a decided gneissic structure.

Fire Tests. This is another of the stones which took on a brownish tinge in the tests. The stones tested at 550° C. developed some slight, but not serious, cracks. At 850° C. on slow cooling, several irregular cracks were caused, and on rapid cooling the stone was seriously cracked, but here, again, the cracks seem to be confined to the coarser seams. Under the flame several pieces were broken from the corner and under the combined action of the flame and the water the cube was very materially injured.

No. 228. 550° slow-cooling test.	No. 229. 550° fast-cooling test.
No. 230. 850° slow-cooling test.	No. 231. 850° fast-cooling test.
No. 232. Flame test.	No. 233. Flame and water test.



Gneiss. Mount Arlington, Morris County.

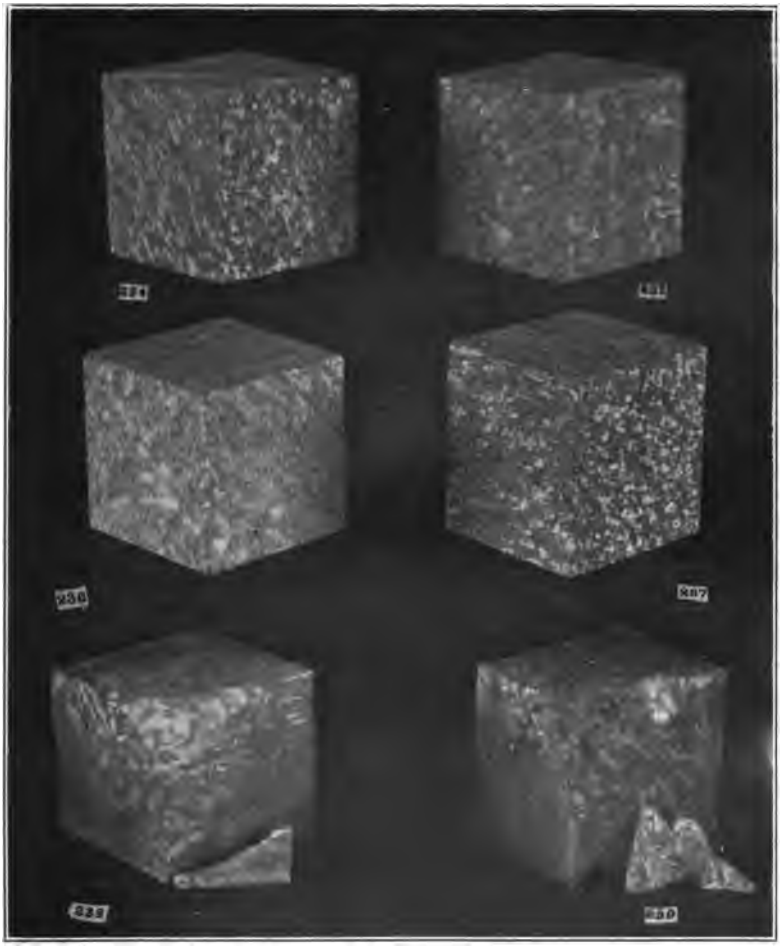
Plate VII.

Gneiss from North Jersey Stone Company's Quarry, Waterloo, Morris County.

The stone, which was tested, has a pinkish color, an uneven texture and a decided gneissic structure. The minerals, which can be seen in the hand specimen, are pink feldspar, light quartz and green hornblende.

Fire Tests. At 550° C. slow cooling this sample remained unaffected and on fast cooling developed but one small crack. The slowly cooled cube, at 850° C., has numerous small irregular cracks, and the fast-cooled one several open cracks. The flame experiments greatly injured the cubes. Not only did they cause pieces to be broken from the exposed corners, but also caused some bad cracks in both samples.

No. 234. 550° slow-cooling test.
No. 235. 550° fast-cooling test.
No. 236. 850° slow-cooling test.
No. 237. 850° fast-cooling test.
No. 238. Flame test.
No. 239. Flame and water test.



Gneiss. Waterloo, Sussex County.

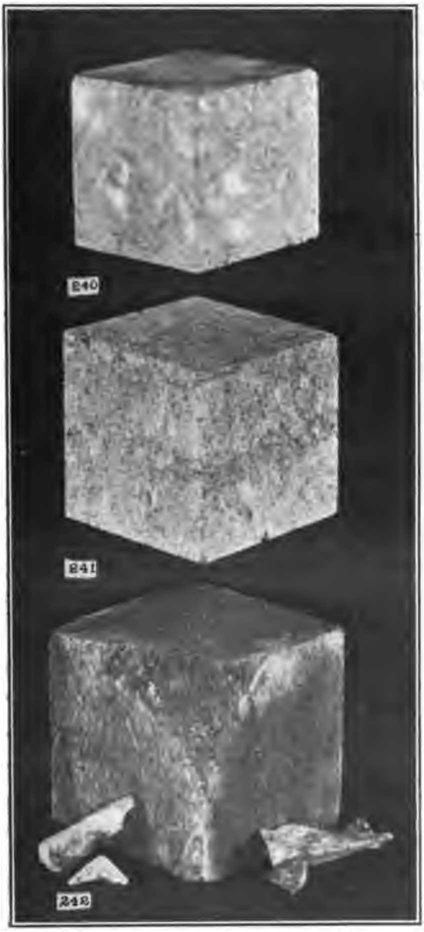
Plate VIII.

Gneiss from Hibernia, Morris County.

This is a gray gneiss of irregular texture, though prevailingly medium in grain, showing light feldspar, smoky quartz and a black hornblende or pyroxene. The quarry has not been worked for a considerable time.

Fire Tests. The cube tested at 550° C. and cooled slowly remained unaffected. The sample heated to 850° C., and cooled rapidly, developed a brown tinge and was quite badly cracked. It looked as if a blow would easily crumble it. The cube, subjected to the flame and water test, was not only badly cracked but also lost several pieces from the corner.

No. 240. 550° slow-cooling test.
No. 241. 850° fast-cooling test.
No. 242. Flame and water test.



Gneiss. Hibernia, Morris County.

Plate IX.

Gneiss from P. Lubey's Quarry, Morristown, Morris County.

The stone from this locality is very variable, both in texture and composition. The cubes, which were tested, have a gneissic structure, a greenish color and are comparatively even in texture. The entire mass has the appearance of a serpentinized rock.

Fire Tests. The stone assumed a brownish tinge. Several small cracks developed on the polished surface after the cube had been heated to 550° C. and slowly cooled. The fast-cooled sample, at this same temperature, developed one bad crack around three sides. It is interesting to note that in this sample the cracks seem to have no definite relation to the direction of the gneissic banding, which is quite different from the usual relation. At 850° C. both cubes were considerably damaged, so much so as to cause them to crumble. While the flame and water test did not disintegrate the cube so much as did the flame test, it developed considerably more cracks, so many as to cause the cube to crumble if struck a slight blow.

No. 243. 550° slow-cooling test.	No. 244. 550° fast-cooling test.
No. 245. 850° slow-cooling test.	No. 246. 850° fast-cooling test.
No. 247. Flame test.	No. 248. Flame and water test.

Note the large crack in 246 and the corner of 247.

Gneiss. Morristown, Morris County.

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PLATE X.

DIABASE FROM F. W. WILSON & CO.'S QUARRY, PLAINFIELD, SOMERSET COUNTY.

This is a very fine-grained rock of a greenish color, qu dense and hard, containing a number of spherules of calcite, so of which are an eighth of an inch in diameter.

Fire Tests. No cube was tested at 550° C. slow cooling. the fast-cooling experiment the stone assumed a brownish tin and showed one irregular crack around three sides, besides so other smaller ones. In the 850° C. tests the samples were brok into a number of small pieces, due to pressure exerted by the caping carbon dioxide formed in the calcination of the calc If the calcite were not present it is quite probable that the st would have acted well. The flame caused some small cra and a number of spalls, while the flame and water broke a la piece from the corner, a few spalls from the sides and develo several small cracks.

No. 200. 550° fast-cooling test.
No. 201. 850° slow-cooling test. No. 202. 850° fast-cooling test.
No. 203. Flame test. No. 204. Flame and water test.

Diabase. Plainfield, Somerset County.

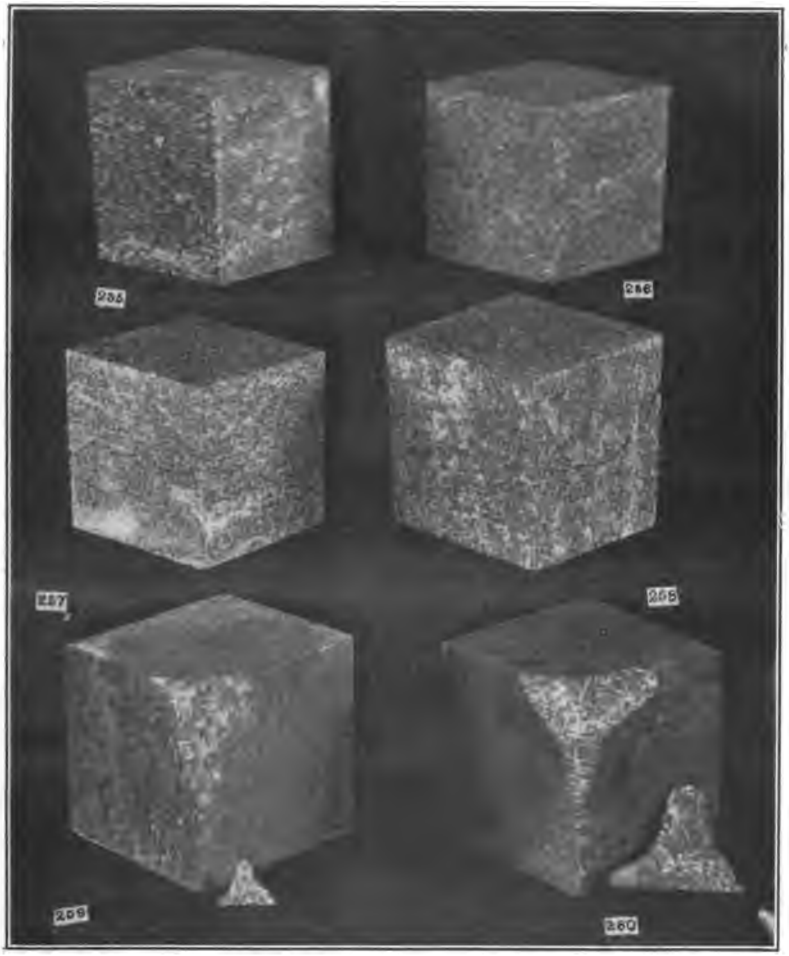
PLATE XI.

DIABASE, B. M. & J. S. SHANLEY'S QUARRY, LAMBERTVILLE, HUNTERDON COUNTY.

This stone has a greyish-black color and a medium texture. In the hand specimen much pyroxene and some feldspar can be recognized.

Fire Tests. In the 550° C. tests the cubes were slightly cracked, the fast-cooled samples slightly more so than the slowly cooled one, but, in both cases, not enough materially to weaken the stone. At 850° C. the cracking was more pronounced, but only in the rapidly cooled sample enough to damage it; here an open crack extends around three sides of the cube. Small pieces were lost and several small cracks were developed in the flame tests.

No. 255. 550° slow-cooling test.	No. 256. 550° fast-cooling test.
No. 257. 850° slow-cooling test.	No. 258. 850° fast-cooling test.
No. 259. Flame test.	No. 260. Flame and water test.



Diabase. Lambertville, Hunterdon County.

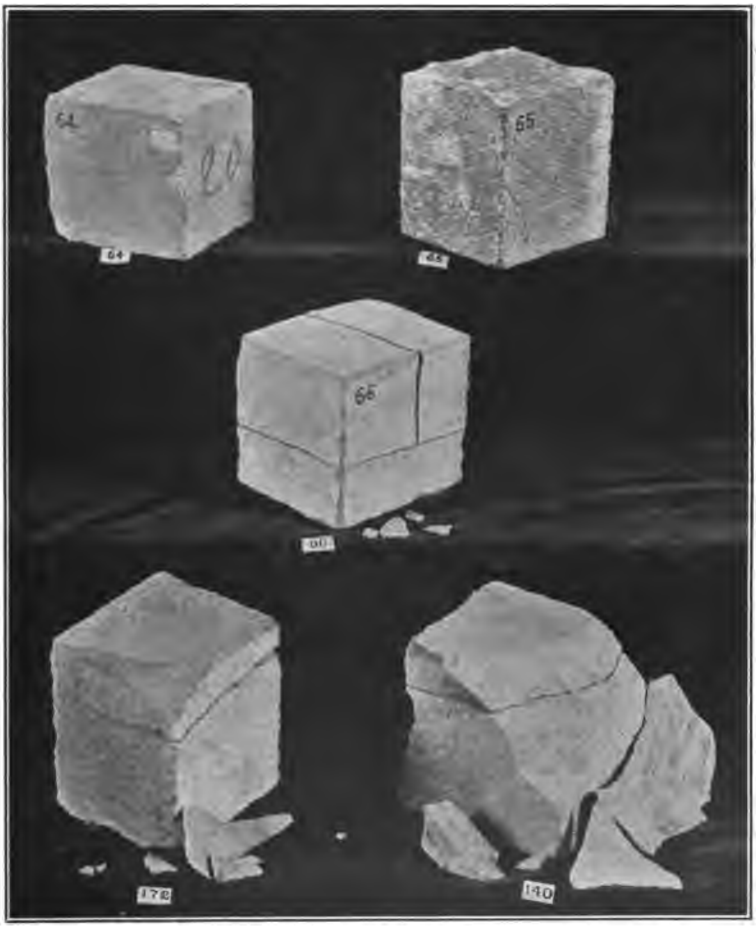
PLATE XII.

SANDSTONE, DE GRAVES BROS. QUARRY, WILBURTHA, MERCER COUNTY.

This stone is very variable, both in color and texture. The good stone is brown, fine-grained, quite compact and hard. Much of it is a poor grade, being soft and porous and of an uneven texture, even being coarse enough to be termed a conglomerate in which quartz and weathered feldspar are easily distinguishable. It is used for structural purposes. The stone, in the thin section, was seen to be composed of angular grains of quartz and much weathered feldspar, cemented rather loosely by limonite, thus leaving many pore spaces. Some plagioclase, biotite scales and ore grains, probably magnetite and pyrite, were also noted. The texture of the section examined is rather fine, the grains averaging one-fifteenth of a millimeter in diameter.

Fire Tests. At 550° C. slow cooling the sample showed one crack around three sides, parallel to the bedding, and the rapidly cooled cube showed several, but not serious cracks. The fast-cooled cube, which was the only one tested at 850° C., was badly damaged. It split into two pieces along the bed, and one of these pieces in turn split into two across the bed. Besides this, several smaller cracks and some spalls were caused. In the flame tests both of the samples were broken in two along the bedding, and other smaller pieces were lost, the cube subjected to the flame and water being damaged to the greater extent.

No. 64. 550° slow-cooling test. No. 65. 550° fast-cooling test.
No. 66. 850° fast-cooling test.
No. 172. Flame test. No. 140. Flame and water test.



Sandstone. Wilburtha, Mercer County.

Plate XIII.

Sandstone, S. B. Twinning Co., Stockton, Hunterdon County.

This is a hard compact stone of a light-gray to bluish color, used as a building stone. The blue variety is rather finer in texture than the lighter stone, which is coarse enough in places to show quartz and weathered feldspar. The entire rock is spotted with limonite stains. The microscope showed angular grains of crushed quartz and weathered feldspar held together rather firmly by silica, some calcite and limonite. Among the feldspars microcline, plagioclase and microperthite were distinguishable. Patches of limonite were numerous. The grains vary somewhat in size, the largest being over a millimeter in diameter and the average about three-fifths of a millimeter.

Fire Tests. Both of the cubes in the 550° C. tests showed but few slight cracks. But at 850° C. the samples were quite badly cracked. Here, as is different from the behavior in most sandstones, the cracks are irregular. This is due to the coarseness of grain and the absence of distinct bedding planes. The samples assumed a slight brown tinge. The cube, which was subjected to the flame and water test, broke into a number of pieces.

No. 47. 550° slow-cooling test. No. 49. 550° fast-cooling test.
No. 46. 850° slow-cooling test. No. 48. 850° fast-cooling test.
No. 141. Flame and water test.

Sandstone. Stockton, Hunterdon County.

Plate XIV.

Sandstone, Stockton Stone Co.'s Quarry, Raven Rock, Hunterdon County.

This sandstone, which is used for building purposes, is light gray in color, has an even texture of a fine grain and is quite compact. The microscope showed that the stone is composed of rather angular to rounded grains of quartz and weathered feldspar cemented by limonite and calcite in a compact manner. Plagioclase, orthoclase, and microcline could be distinguished and a few grains, probably of magnetite and pyrite are scattered through the section. The grains average three-tenths of a millimeter in diameter.

Fire Tests. The rapidly cooled sample at 550° C. developed a few more cracks than the slowly cooled one, but, in both cases the injury was slight. At 850° C., however, the cubes were badly injured. The slowly cooled stone showed up some irregular cracks, besides being broken into two. While the fast-cooled cube was not broken into two pieces it was considerably cracked. In both of the flame tests the exposed corners were broken.

No. 50. 550° slow-cooling test.
No. 52. 850° slow-cooling test.
No. 173. Flame test.
No. 51. 550° fast-cooling test.
No. 53. 850° fast-cooling test.
No. 142. Flame and water test.

Sandstone. Raven Rock, Hunterdon County.

PLATE XV.

SANDSTONE, W. E. BARTLE'S QUARRY, MARTINSVILLE, SOMERSET COUNTY.

This stone, which is widely used for building purposes, is light gray in color, quite fine-grained and even in texture and fairly compact. The microscope showed that the grains are angular to rounded, average three-twentieths of a millimeter in size and are mostly quartz, though there is much weathered feldspar and some mica present. The cement is largely calcite, with some limonite. A few grains of magnitite were noted in the section.

Fire Tests. The rapidly cooled cube at 550° C. remained uninjured, while the slowly cooled sample developed a small crack. This stone also took on a brownish tinge. At 850° C., upon fast cooling, the stone showed one bad crack around three sides. Under the flame several small pieces were broken from the front edge, and under the flame and water test a much larger portion was lost.

No. 72. 550° slow-cooling test. No. 73. 550° fast-cooling test.
No. 74. 850° fast-cooling test.
No. 175. Flame test. No. 144. Flame and water test.

Sandstone. Martinsville, Somerset County.

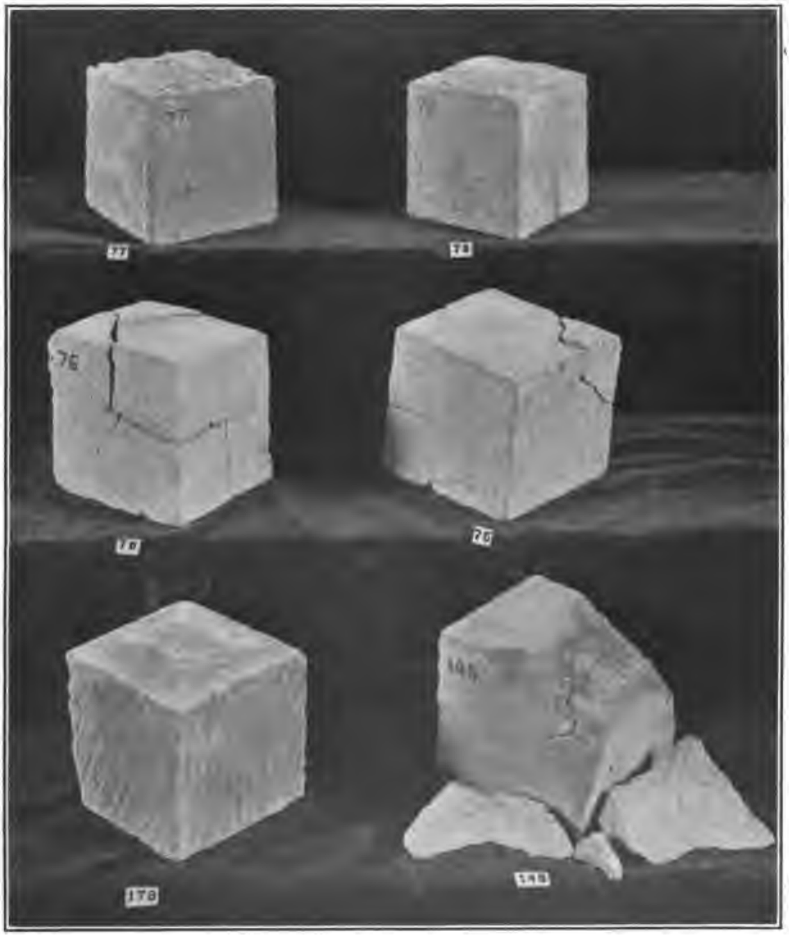
PLATE XVI.

SANDSTONE, F. W. SHRUMP'S QUARRY, PLEASANTDALE, ESSEX COUNTY.

This building stone, brown in color, is quite variable. The good stone is fairly even grained and fine in texture, but it grades into a loose, coarse-grained stone, which, in places, splits very easily along the bed because of the presence of numerous scales of mica. Under the microscope the grains appeared to be sub-angular and are held together by a limonite cement. The stone is not very compact. The grains, which average one-tenth of a millimeter in diameter, are largely quartz and weathered feldspar, with some weathered mica scales and a few apatites.

Fire Tests. Little damage was done in the 550° C. tests; the sample which was cooled slowly remaining unchanged and only one insignificant crack developing in the fast-cooled sample. At 850° C. the cubes suffered great injury; the slowly cooled stone split into two pieces and was otherwise badly cracked and the rapidly cooled sample was so injured as to make it worthless. Under the flame the stone resisted well, being cracked only slightly at the front edge, but under the combined action of the flame and water the sample was badly broken.

No. 77. 550° slow-cooling test.
No. 76. 850° slow-cooling test.
No. 179. Flame test.
No. 78. 550° fast-cooling test.
No. 75. 850° fast-cooling test.
No. 148. Flame and water test.



Sandstone. Pleasantdale, Essex County.

PLATE XVII.

SANDSTONE, BELLEVILLE STONE AND QUARRY COMPANY, AVONDALE, ESSEX COUNTY.

The stone from this extensive quarry is a brown stone of a rather medium texture, firm and compact. The texture, as shown in the thin section, varies somewhat, the average size of the angular and subangular grains being one-third of a millimeter, though there is much of a coarser and finer texture. Quartz and cloudy feldspar, with some plagioclase, make up most of the stone, though many colorless scales of mica are scattered through the mass. The cementing material is limonite and calcite in about equal proportions and the stone appears quite compact and firm.

Fire Tests. The cube tested at 550° C. and cooled without the action of water remained unaffected. The fast-cooled sample at 850° C. was split into two pieces along the bed and was also slightly darkened in color. The sample put through the flame split in two, showed several cracks and lost several pieces from the exposed edge.

No. 108. 550° slow-cooling test. No. 180. Flame test.
No. 111. 850° fast-cooling test.

Another sample, from the same locality, is grayish brown in color and of a coarser and more uneven texture, the latter, as shown by the microscope, varying considerably. Some grains exceed a millimeter in size, while there is much that is finer. Quartz and feldspar with some microcline and microperthite are the sole constituents, with the exception of a few scales of colorless mica. The cementing material, as in the other sample from this locality, is limonite and calcite, though there is less of the latter in this stone than in the brownstone. This sample is more compact than the brownstone.

Fire Tests. The cube tested at the lower temperature remained uninjured, but assumed a brownish tinge. At 850° C. on slow cooling there were developed two slight cracks of marked irregularity, differing in this respect from those in the finer-grained stone from this same locality. It would seem, then, that the coarseness of grain caused an irregularity in the cracking. The flame and water caused the cube to be so broken as to make it worthless.

No. 109. 550° fast-cooling test. No. 149. Flame and water test.
No. 110. 850° slow-cooling test.

Sandstone. Avondale, Essex County.

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Plate XVIII.

Sandstone, Geo. Bayliss' Quarry, North Arlington, Hudson County.

This stone, where fresh, is light gray in color, but, for the most part, it is stained with iron and copper compounds. Where fresh it is hard, compact and fine grained, but because of the amount of weathering it has undergone, it is rather loose and porous. It is locally used as a building stone. In thin section the texture was seen to vary somewhat. Most of the mass is fine grained, though some of the grains reach the size of a millimeter. The stone is made up of fairly rounded fragments of somewhat cracked quartz and cloudy feldspar, the latter mineral being the more abundant. As a whole the mass is loosely cemented by limonite, but in places there seemed also to be a cementing material made up of finely crystalline quartz and feldspar.

Fire Tests. But three samples of this stone were tested. The 550° C. slowly cooled cube remained uninjured, but assumed a slight brown tinge. The fast-cooled cube at this same temperature developed one small crack across one corner. The sample after being subjected to the flame and water test went to pieces.

No. 80. 550° slow-cooling test. No. 79. 550° fast-cooling test.
No. 150. Flame and water test.

Sandstone. North Arlington, Hudson County.

Plate XIX.

Sandstone, J. Gamblee and Son, Closter, Bergen County.

This stone is coarse grained and light gray, showing, in the hand specimen, weathered feldspar and quartz. It varies somewhat in texture, yet is all quite coarse. The microscope showed that the mass is rather firmly cemented together and the grains are well interlocked. The cementing material is largely limonite, but the secondary enlargement of both the quartz and feldspar has made the stone firm and compact. The grains are irregular, angular and quite variable in size, the largest being over a millimeter in diameter. Quartz, showing evidences of crushing, and feldspar make up the body of the stone in about equal proportions. The feldspar, which is somewhat weathered, is mainly an acid plagioclase and microline, with some microperthite and microcline microperthite. A few zircons and apatites were also noted in the section.

Fire Tests. Both of the cubes tested at 550° C. remained uninjured. The 850° C. slow-cooling test caused the stone to lose most of its durability, for it was split into a number of pieces by irregular cracks. In the flame test a small piece was broken from the exposed corner. Under the action of the flame and water the sample seems to have remained uninjured.

No. 70. 550° slow-cooling test. No. 71. 550° fast-cooling test.
No. 69. 850° fast-cooling test.
No. 181. Flame test. No. 151. Flame and water test.

Sandstone. Closter, Bergen County.

5* GEOL

Plate XX.

White Limestone, B. Nicoll & Co., Franklin Furnace, Sussex County.

This is an exceedingly coarse-grained, well-crystallized white limestone, some of the crystals of which are over two inches in size. The color is white to pale bluish. Scattered through the mass are scales of mica and graphite and other dark minerals. It is not used as a building stone.

Fire Tests. A sample, after having been heated to 550° C. and cooled rapidly remained apparently uninjured. The 850° C. tests badly damaged the cubes. Both were considerably cracked, calcined and crumbled. Several cracks were caused and several small pieces were broken from the edge of the sample in the flame test and in the flame and water experiment large pieces were lost and small cracks developed.

No. 211. 550° fast-cooling test.

No. 212. 850° slow-cooling test. No. 213. 850° fast-cooling test.

No. 214. Flame test. No. 215. Flame and water test.

White Limestone (Marble). Franklin Furnace, Sussex County.

Plate XXI.

Limestone, O'Donnel and McManiman's Quarry, Newton, Sussex County.

This is a fine-grained, crystalline, blue and hard stone in which veins of white calcite locally occur. It is highly magnesian.

Fire Tests. Both cubes, in the 550° C. experiments remained unaffected. In the 850° C. tests the calcination was slight, because the stone is largely dolomitic. The slowly cooled sample shows several small and irregular cracks, the fast-cooled sample likewise shows several small cracks, and it flaked a little because of the calcination, but in both cases the injury is not great. In the flame tests the cubes were considerably affected, being broken into pieces on the exposed corners and edges.

No. 216. 550° slow-cooling test.
No. 217. 550° fast-cooling test.
No. 218. 850° slow-cooling test.
No. 219. 850° fast-cooling test.
No. 220. Flame test.
No. 221. Flame and water test.

Limestone. Newton, Sussex County.

Plate XXII.

Limestone, Phillipsburg, Warren County.

This is a fine-grained, hard, crystalline dolomitic stone of a bluish color, in which are numerous, coarsely crystalline veins of calcite.

Fire Tests. The 550° C. slowly cooled cube remained unaffected, but the rapidly cooled sample developed several small cracks. In both tests at 850° C. irregular cracks were caused along the calcite veins and there was some flaking due to the slight calcination. The flame test broke a small piece from the corner and caused several cracks. The combined action of the flame and water caused the sample to be broken into a number of pieces.

No. 249. 550° slow-cooling test.
No. 250. 550° fast-cooling test.
No. 251. 850° slow-cooling test.
No. 252. 850° fast-cooling test.
No. 253. Flame test.
No. 254. Flame and water test.

Limestone. Phillipsburg, Warren County.

PLATE XXIII.

ARGILLITE ROCK, MARGERUM BROS., PRINCETON, MERCER COUNTY.

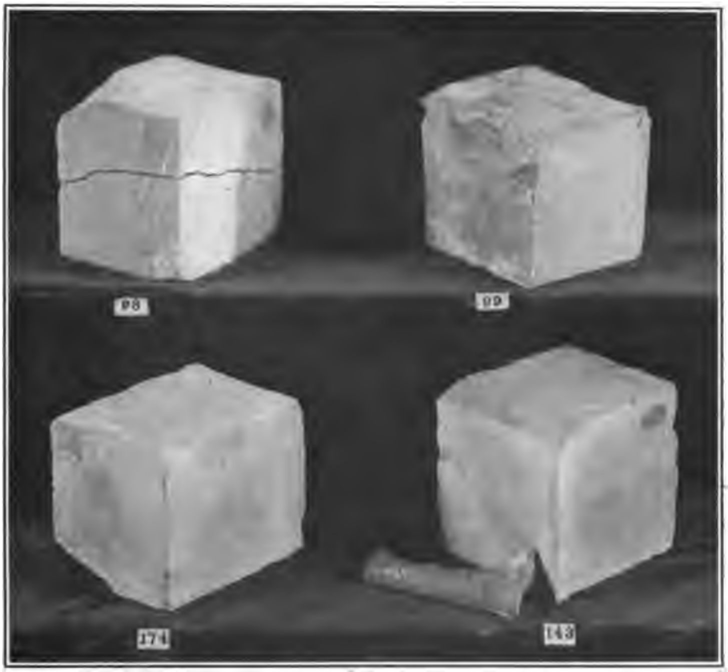
The stone from this locality is an extremely fine-grained rock of a slate color. It looks much like a shale or a slate and splits readily along the bedding planes. It is used for structural work.

The microscope reveals the presence of many cavities filled or partially filled with opal. Some little quartz grains are scattered through the mass, which seems to be an extremely fine-grained calcareous material, mixed with much clay.

Fire Tests. Upon slow cooling, after being heated to 550° C., the cube was split along the bedding and showed other cracks. Upon cooling rapidly from the same temperature, some transverse cracks were developed, but the worse cracks were parallel to the bedding. The flame test developed one slight crack along the bed and around three sides, while the flame and water together broke a small piece off the upper edge, besides cracking the sample around three sides along the bedding.

No. 98. 550° slow-cooling test.
No. 99. 550° fast-cooling test.
No. 178. Flame test.
No. 143. Flame and water test.

Dec. 15, 1907.



Argillite. Princeton, Mercer County.

PART II.

The Glass-Sand Industry of New Jersey.

By HENRY B. KÜMMEL and R. B. GAGE.

The Glass-Sand Industry of New Jersey.

BY HENRY B. KÜMMEL AND R. B. GAGE.

Introduction.—This report on the glass sands is part of a larger investigation of the sand deposits of the State, commenced nearly two years ago by the Geological Survey. Since numerous inquiries have been received for information regarding the glass sands in particular, the following paper has been prepared for publication at this time.

Condition of the industry.—During the last ten or fifteen years the glass-sand industry of this State has witnessed a marked decline in the price received for sand, due to the introduction of labor-saving machinery and competition. There is also a tendency towards consolidation, which has resulted in the partial elimination of the small producer. This drop in price has stopped the mining of glass sand at some pits and caused the installation of modern plants to handle the sand on a larger scale at others. Those companies which have ceased to mine this grade of sand are mixing their glass sand with the top layers of the sandy loam and clay and selling the mixture for foundry purposes. This is particularly true when the glass sand is of an inferior grade, or else very small in amount compared to the foundry sand mined.

Since there is practically little or no glass sand exported from the State, any cause that has a tendency to increase or decrease the prosperity of the glass industry of the State will naturally have a corresponding effect on the glass-sand industry. A rise in the price of the manufactured article, or decrease in the cost of producing the same, will encourage the manufacturer to enlarge his output, which will increase the demand for sand. The cost of labor being practically the same throughout the country,

the principal remaining factors that determine the prosperity of a glass industry in any particular locality are cost of fuel, sand and freight rates.

The cost of fuel in the New Jersey field is high when compared to the cheap fuel available in the natural gas fields of Indiana and Kansas, but experience has shown that the supply of natural gas is far from inexhaustible, and within recent years there have been many removals from the waning gas fields of Indiana to the new gas fields of Kansas. Even when compared with other fields using coal, the location of the New Jersey field is not particularly advantageous, although it is not greatly removed from the coal fields of Eastern Pennsylvania. It has, however, the tremendous advantage of close proximity to the markets of the large cities of the East.

While the individual sand deposits of New Jersey are not so large as those of the Middle West or Pennsylvania, they can be operated much cheaper and with a much smaller initial investment. The latter deposits are mostly sandstone, that must be blasted out and crushed before washing. Often these deposits are capped by shale or limestone of so great thickness as to compel mining by tunneling, instead of in an open pit. The New Jersey deposits are always capped by more or less sandy gravel, but this capping is not always a detriment in digging, for it is sometimes profitably sold for foundry purposes. Again the New Jersey producer gets 90 cents per ton for his product, compared with 60 to 65 cents per ton in Illinois and Missouri.[1]

Area of the field.—Throughout the greater part of the southern half of the State, the surface gravel is underlaid by beds of sand. In some places these beds have been found to be 90 feet thick. Along the river banks they can be plainly seen where undercutting of the bluff has exposed them. These beds are often pure enough to be of value for glass, and are dug for this purpose. The principal localities in which they are being dug to-day are (1), along the Maurice River below Millville; (2), the region around Vineland, and (3), that around Williamstown,

[1] U. S. Geological Survey, Bulletin No. 285, p. 461.

although twenty-five years ago glass sand was being mined as far east as Egg Harbor and west to Salem. The drop in the price of sand was probably the controlling factor that caused the contraction in the area of the productive field. Since glass sand is widespread geographically, and the supply is always greatly in excess of the demand, only those pits which can be worked most cheaply have continued in operation.

On account of the bulky nature of the sand, the cost of transportation is one of the leading items that determines the value of a pit, and consequently its life. This naturally confines the productive area of a glass-sand field to the vicinity of a railroad or navigable river. Practically every producing pit in southern New Jersey is less than one mile from a railroad or is along a navigable stream, although there is no doubt but that good undeveloped deposits of glass sand exist elsewhere in this region. Since cheap transportation is so vital a factor, there is small chance for the immediate development of the more distant areas. Even the territory that is within a mile of the railroads has not been thoroughly developed, or even tested.

The producing fields.—The present producing field is naturally divided into three districts, the Maurice River, the South Vineland and the Williamstown.[1]

The Maurice River district is just south of Millville, along the Maurice River, where the beds of sand can be seen for several miles along the river banks. The sand from this district is all shipped in barges, which fact naturally confines the pits to the banks of the river or a short distance inland.

The West Jersey railroad traverses the South Vineland district, the village of South Vineland being about its center. All the pits are within ½ to ¾ of a mile of the railroad, and are scattered at irregular intervals for about 3 miles along it. This district would no doubt be much enlarged if the demand increased or the price rose sufficiently to justify operations at a greater distance from the railroad than at present.

The Williamstown district covers a much larger area than either of the other two. The pits are scattered along the Wil-

[1]Some glass sand is dug also at isolated points not included in these districts, as at Jamesburg, Middlesex county.

liamstown and Delaware railroad from Downer nearly to Atco, a distance of 10 miles. In most cases they are widely separated, leaving plenty of undeveloped territory adjacent to the railroad. . Some new deposits have recently been discovered in this field, and are being developed. Judging from the size of the field, much good glass sand within this area is probably as yet undiscovered. If such is the case, this district alone could supply the demands of the glass industry for years to come.

Description of the deposits.—All the glass-sand deposits of southern New Jersey are capped by layers of gravel, sand and loam, varying in thickness from 1 to 15 feet or more. Below Millville, along the Maurice River, the low hills are capped by gravel deposits, the thickness of this covering depending on the height of the hill, as little gravel is found in places below the top of the sand horizon proper, except as small pockets in the sand beds. These gravel deposits are, in many instances, of value for foundry purposes, road metal and other uses. The glass sands of this locality that are of commercial value all lie from 30 feet above sea level to a shallow depth below. The deposits are mostly on the west bank of the river, where the erosion of the river and its tributaries has exposed them.

There is no doubt but that the sand beds extend an indefinite distance back from the river under the gravel capping, and at one point a small pit is now being worked about a mile back from the river. While there is no reason to suppose that the sand beds pinch out away from the river, nevertheless, the character of the sand may change from place to place so as to ruin it for glass purposes. The increased expense of opening up and working a pit any distance from the river has discouraged operators from trying to discover new deposits in that direction.

Several different grades of sand, sometimes as many as five, frequently occur in a single bank. These different layers vary not alone in the iron and clay content, but also in the size and character of the sand grains. The various layers are frequently separated by thin sheets of clay. Sometimes one grade changes abruptly into another, while elsewhere there may be a gradual transition from a fine to a coarse grain, or vice versa. Changes in the size of the grains are frequently accompanied by varia-

tions in the clay and iron content. Not uncommonly, the sand immediately below the gravel beds is fine grained, rich in clay and contains too much iron for glass use, but it is often mined and sold for foundry purposes. As the grains increase in size, the beds often become whiter with the lowering of the iron and clay content, until the best grade of glass sand is reached near the water level. Although the largest grains do not always occur at or below the water level, the beds of these grains are mostly lower in clay and other impurities than when composed of small grains.

The topography of the South Vineland district is not so broken as that near Millville. The land is slightly rolling and mostly under cultivation. The overlying gravel, averaging only from 3 to 5 feet, does not form so thick a covering as in the Maurice River district. Immediately below the surface layer, the sand is sometimes finer grained than the glass-sand grade, but often differs only in the amount of the clay and iron content. In the latter case, the sand gradually gets purer with depth until suitable for glass. The ground waters apparently contain very little iron, as often the best grade of sand is found below the water level. Some of these pits have been worked over large areas, but seldom deeper than the water level. In mining, the stripping has been thrown on the mined ground, and no doubt has often covered first-class sand. From the cursory examination made, it was impossible to tell whether the deposits pinched out at the edges or gradually became valueless for glass by becoming impregnated with iron.

Throughout the white sand there are frequently iron-stained streaks or seams, which are generally quite narrow and cause little or no trouble. Sometimes, however, they are 6 to 10 inches thick, and then must be separated from the purer sand before washing. The sand above, between and below them may be first-class glass sand.

Pockets of blue clay, sometimes of considerable size, occur not infrequently in the sand beds, but being sharply separated from them cause comparatively little trouble in mining. Sometimes layers of clay 2 to 3 feet thick are found just below the gravel covering resting on top of the glass-sand beds.

The Williamstown district resembles the South Vineland district very much in topography, character and depth of the gravel covering. The fine, loamy foundry sand sometimes is wanting between the gravel layer and the white glass sand beneath. Often in different parts of the same bank, the foundry sand occurs at the level elsewhere occupied by the glass sand. In some of these pits, the best sand is found below the water level, while in other instances the percolating iron-bearing waters have ruined the deposit below this point. In certain spots these chalybeate waters have coated the grains of the entire glass sand beds, rendering the deposit valueless at this point. Lenses of a clean, sharp small-pebbled gravel, which are of a different character than the gravel covering, are found in some of these sand beds.

Mining methods.—There are two general methods of mining in use throughout the glass-sand field. By the older method, after stripping, the sand is shoveled into carts or cars and hauled to the washer. By the newer method, the sand, suspended in water, is pumped from the bottom of the pit and forced through a 4 to 6-inch pipe to the washer.

The former method has the advantage of producing a higher grade of sand than the latter method, where there is much variation in the character of the beds, as the impure sand can be separated to a certain degree and discarded before washing, so that deposits can be mined by this method that would be worthless if mined by the latter. The depth to which deposits can be dug by the old method is mostly determined by the height to which the ground water rises in the pit, as little sand is mined below the water level. In some pits this objection is of little importance, as the sands are valueless below this point, while in other instances the best grade of glass sand is found below this level. The cost of handling sand by this method, however, is so much greater than by the pumping method that its advantages are clearly outweighed by this one drawback, and therefore it is being rapidly replaced by the modern method at all pits where conditions are not absolutely prohibitory.

A deposit to be mined by the pumping method must be fairly uniform and free from iron-stained seams of any considerable thickness. One containing seams could not be mined at all by

Pumping Plant. R. O. Bidwell's Glass-Sand Pit, South Vineland.

this method, for washing would not remove these iron-stained grains, and they could not be removed otherwise, unless the seams are all found above the water level. In this case, they can be dug out separately before the sand falls into the water. The bottom of the deposit must also be a few feet below the level of the ground water, of which there must be a sufficient supply to keep the pit well filled in addition to furnishing what is needed for washing. In Plate XXIV this method of mining is fairly well shown. The white bank on the right is the glass sand, from which the overburden has been stripped off for a few yards back. On the left is the waste pile of stripping which has been wheeled or carted across the bridge shown in the cut and dumped on the mined ground. Between these two banks a small, flat-bottomed boat, containing a suction pump and such other machinery as is necessary for pumping the sand and water, is seen in operation. The intake-pipe is kept a few feet under water and within a short distance of the sand bank. When this pipe is kept at the proper distance from the bank, the water pumped will contain from 20 to 30 per cent. sand, the amount of sand carried and the size of the grains increasing with the velocity of the water. The mixture of sand and water is forced directly to the washer through the pipe seen leading off to the left.

Any clay adhering to the sand grains is softened and detached from the grains during mining and washing, owing to the preliminary soaking to which it is subjected. With a medium-sized, well-equipped plant, 10 men can easily mine and wash 250 tons of sand per day of 10 hours.

The digging of glass sand requires quite an initial investment to open up a deposit and install a modern plant. Strong competition between the different producers has lowered the price, so that, as already mentioned, at not a few pits which formerly produced some glass sand, none is now mined. Those companies which do not adopt the newer methods will probably soon find it unprofitable to mine at the lower price, and must either install an up-to-date plant or else cease producing this grade of sand.

Method of washing.—The method of washing glass sand in use throughout the New Jersey glass field is a comparatively

simple process. The sand is washed into the upper end of an inclined revolving cylindrical screen, about 4 feet long and 18 inches in diameter, and gradually works towards the lower end as the cylinder revolves. This screen allows all grains smaller than $^1/_{40}$th of an inch (30 mesh) in diameter, to pass through into a trough below. Grains larger than this size pass out of the lower end of the cylinder and are rejected. The clay and loam pass through the sieve together with the glass sand, so that this preliminary treatment eliminates only the material too coarse for the glass manufacturer.

After passing through the screen, the sand is caried up a series of inclined flumes by endless chains and scrubbers (Plate XXV). As the sand passes slowly up these flumes the water runs back, carrying whatever clay and fine sand remains suspended in it. Impurities too heavy to remain suspended pass on with the sand, which is at last dumped in a pile outside the washer, where the excess of water is allowed to drain off before loading into cars. The scrubbers move so slowly up the nearly level flumes that only the fine clay and loam is removed. It is not uncommon to find in the washed sand ½ to 1 per cent. of the grains so fine that they will pass a 200-mesh sieve, and often 4 per cent. are finer than the 120-mesh sieve. If the scrubbers were made to travel faster or the flumes given a more inclined position, much more of this fine material would be removed, a result to be desired.

PHYSICAL PROPERTIES.

The physical character of a glass sand is of importance, although not so much so as the chemical composition.

Shape.—It is the prevailing opinion throughout the glass-sand field that the sand grains should be sharp and angular, never rounded and smooth. This opinion does not appear to be altogether well founded, as the ordinary grades of glass, as well as the fine flint wares, are being successfully made in the Mississippi Valley field from sands composed entirely of the latter type.[1]

[1] U. S. Geological Survey, Bulletin No. 285.

Washing Plant. R. O. Bidwell Glass-Sand Pit, South Vineland.

The New Jersey sands are prevailingly subangular. Most of the grains show irregular fracture surfaces, angles and edges, which in the case of those larger than $^1/_{55}$ of an inch (40-mesh) are more or less rounded, while of the grains smaller than $^1/_{100}$ of an inch there are almost none which are not sharply angular. The grains of intermediate size are slightly worn, but not enough to change greatly their original shape. On the whole the sands would be classed as sharp and angular rather than round and smooth. The samples examined from the South Vineland district are somewhat more worn than those from the Williamstown.

Plates XXVI and XXVII are photomicrographs of the sands, magnified 10:5 diameters, which show better than words their shape.

Size.—The grains should not be too small or too large, and as uniform in size as possible. If the majority of the grains have a less diameter than 0.136 mm. (passing a sieve having 120 meshes per linear inch), the sand is said to "burn out" in the batch and will not produce as much glass per unit as when composed of coarser grains. The fine grains also have a tendency to settle to the bottom of the batch, thus preventing the forming of a homogeneous mixture. When the grains are uniformly larger than 0.64 mm. (30 mesh) in diameter, more time is required to fuse them than otherwise. This lowers the amount of sand each furnace can melt per day and increases the cost of the glass produced.

The determination of the sizes of the grains can be best made by passing a known amount of sand through a series of sieves[1] arranged in regular order, that with the coarsest mesh being at the top. A convenient quantity of the sand having been placed in the top sieve, the whole series, held firmly together is given a certain number of shakes, either by hand or in a machine, more rapid and satisfactory results being secured with a machine. After shaking, the amount found in the pan under the bottom sieve is weighed and the weight recorded. Then the amount found on the bottom sieve is added to that in the pan and the

[1] A very convenient series of sieves reading from the bottom up according to mesh are 200, 140, 120, 100, 80, 60, 40, 30, 24, 18, 10, ¼, $^5/_{16}$ and ½.

whole weighed and recorded. This is continued until that found on all the sieves has been weighed, and the amount that has passed each sieve determined. If a weight of 100 grams were originally taken, the percentage which has passed each sieve can be read directly from these weights without further calculation.

Samples of washed glass sand from many of the deposits in the State have been examined by the above method, with the results shown in the following table:

Table showing the per cent. of grains passing the different sieves.

MESH OF SIEVE.	661B	664A	665C	666A	669A	670B	671A	672A	663
10, ...	99.8	......	......	99.7	......	......	......	99.8	99.8
18, ...	99.7	......	......	99.5	......	......	......	99.2	99.7
24, ...	99.4	......	99.5	98.4	......	......	99.8	98.5	99.3
30, ...	98.3	99.8	98.6	93.7	99.7	99.8	99.1	95.8	96.4
40, ...	93.7	97.8	81.9	73.6	98.8	99.2	96.3	85.4	61.4
60, ...	53.1	18.8	11.4	22.2	19.5	47.8	40.4	25.4	7.4
80, ...	26.5	6.2	3.7	11.1	7.7	16.2	22.6	11.5	1.8
120, ...	5.2	1.7	0.5	2.5	1.6	2.6	4.4	1.4	0.2
140, ...	2.3	1.1	0.2	1.4	1.1	1.5	2.2	0.5	0.0
200, ...	0.7	0.5	0.1	0.4	0.5	0.7	0.8	0.0	0.0

From the above table it is apparent that in none of the samples is there much material which will pass a 120-mesh sieve (openings $^1/_{187}$ inch) and very little (except in No. 666A and 663) which is coarser than a 40-mesh sieve (openings $^1/_{55}$ inch). In many of the samples about 60 per cent. of the grains are between $^1/_{55}$ and $^1/_{90}$ inches in diameter (40 and 60-mesh). Sample 663 of the table is a Pennsylvania sand cleaned by an air-blast process rather than by washing. It has 35 per cent. of the grains between $^1/_{40}$ and $^1/_{55}$ inches in diameter and 54 per cent. between $^1/_{55}$ and $^1/_{90}$ inches, with an entire absence of grains smaller than $^1/_{210}$ inches (140 mesh) and practically none as small as $^1/_{187}$ inches (120 mesh). These statements and the above table indicate the comparative uniformity in the size of grain of a good glass sand.

Examination of a number of unwashed sands disclosed a slightly larger percentage, as compared to the washed sands, of

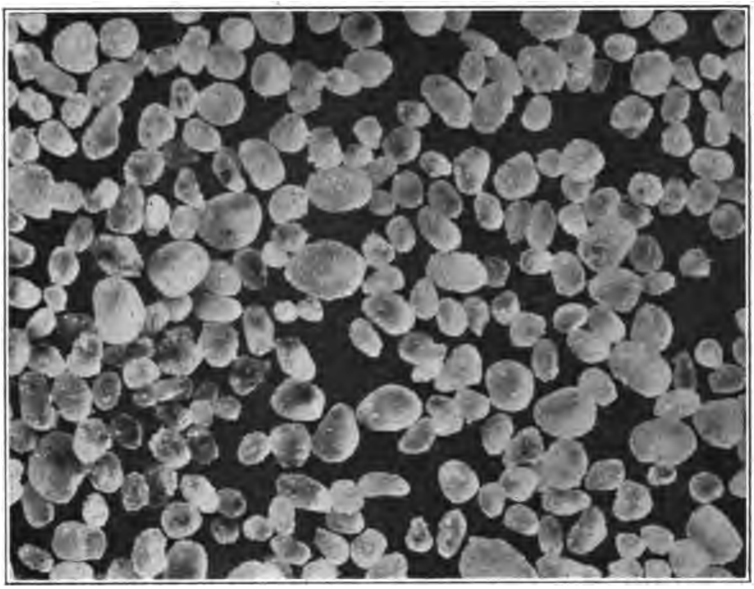


Fig. 1.
Well-rounded sand grains from an Ordovician Dolomite, Cushman, Ark. (van Ingen)—magnified 15 diam.

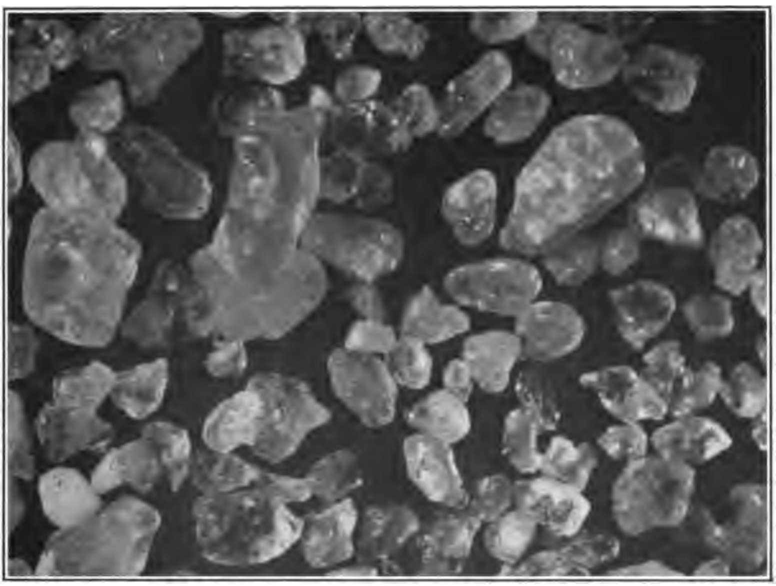


Fig. 2.
Sand grains retained on a 40-mesh sieve, x 10½ diam. Reading Sand Company, Penbryn.

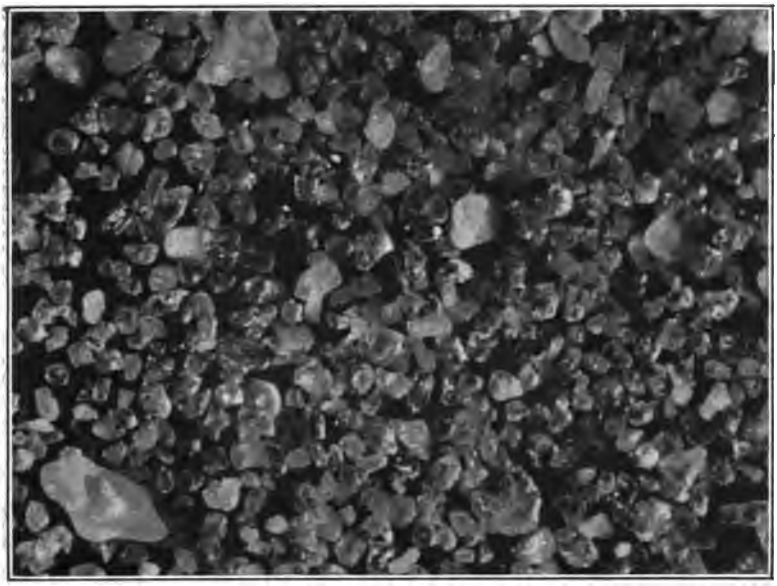


Fig. 1.
Sand from Weirick and Fields. Radix. x 10½ diam. Note a few rounded grains.

Fig. 2.
Sand from Crystal Sand Company, South Vineland, x 10½ diam.

the sizes rejected in the process of washing already described, but these differences are not striking.

Impurities.—Under the microscope the quartz grains appear as clear, transparent crystals. Grains of milky or colored quartz are very rare, and there is little evidence of any impurities such as clay or iron oxide attached to the grains of either the washed or unwashed sands. Small grains of other minerals than quartz are quite numerous in the Williamstown deposits, but much less so in the samples from the other two fields. These foreign grains are fairly uniform in size, well-rounded and mostly less than 0.21 mm. ($^1/_{121}$ inch) in diameter, and will pass an 80-mesh sieve. They were found to be chiefly leucoxene, rutile, ilmenite and sphene.[1] Since the quartz grains are almost chemically pure themselves and have practically no impurities attached to them, these minerals must contain the greater part of the iron, titanium, etc., which chemical analysis shows are present in the sands. It follows that if they can be eliminated the quality of the sand will be much improved.

Chemical composition.—An absolutely pure quartz sand would be 100 per cent. silica (SiO_2), but an accurate chemical analysis of even the best glass sands always shows small amounts of the following substances: iron, alumina, titanium oxide, lime, magnesia and organic matter. These are due to other mineral grains than quartz usually present in the sand, such as mica, magnetite, feldspar more or less altered to kaolin, ilmenite, sphene, rutile, etc., or to films of iron oxide or clay coating the quartz grains. Some of these cause little or no trouble in a glass sand when present in small amounts, while others are very injurious when present even in amounts not to exceed $^1/_{100}$ of 1 per cent. Chief among these detrimental substances are the oxides of iron which, if not already in the ferrous state, are reduced to it in the furnace, and give the glass a green color. Such substances, as the carbonate of lime which may occur as bits of shell or ground-up limestone can hardly be classed as impurities, since they are added to the sand in the manufacture of glass, although when present in the sand they lower the percentage of silica, as shown by the

[1] Examined and identified by Prof. J. Volney Lewis, of Rutgers College.

analysis. The oxides of sodium and potassium which are shown in small amounts in some analyses of glass sands are not to be regarded as impurities, as they also are added in making up the glass batch. A small percentage of clay causes little trouble providing the clay contains no iron and very little magnesia, but this is very seldom the case. The water coming from the scrubbers is almost always a dirty yellow color which indicates the presence of clay containing considerable iron, some or all of which is in the ferric state. The following chemical analyses of New Jersey washed glass sands and of one Pennsylvania sand (663) have been made especially for this report by the junior author:

Sample No.	Silica SiO_2.	Iron Oxide Fe_2O_3.	Alumina Al_2O_3.	Titanium Dioxide TiO_2.	Lime CaO.	Magnesia MgO.	Organic Matter and Moisture.
661B, ...	98.93 %	0.0222%	0.4686%	0.269 %	0.010%	0.008%	0.29 %
662A, ...	99.59 "	0.0071 "	0.1447 "	0.0728 "	0.010 "	0.007 "	0.172 "
663, ...	99.72 "	0.0017 "	0.1203 "	0.0147 "	0.007 "	0.008 "	0.134 "
664B, ...	99.40 "	0.0058 "	0.2752 "	0.0737 "	0.008 "	0.012 "	0.231 "
665C, ...	99.62 "	0.0047 "	0.142 "	0.0543 "	0.01 "	0.005 "	0.162 "
666A, ...	99.54 "	0.0039 "	0.2245 "	0.0476 "	0.007 "	0.009 "	0.166 "
667A, ...	99.35 "	0.0086 "	0.3392 "	0.1302 "	0.017 "	0.005 "	0.156 "
668A, ...	99.52 "	0.0096 "	0.1856 "	0.0868 "	0.006 "	0.007 "	0.19 "
669A, ...	99.42 "	0.0068 "	0.276 "	0.117 "	0.01 "	0.018 "	0.156 "
669B, ...	99.48 "	0.0075 "	0.204 "	0.1215 "	0.006 "	0.009 "	0.17 "
670A, ...	99.39 "	0.0086 "	0.2345 "	0.1475 "	0.005 "	0.007 "	0.21 "
671A, ...	99.11 "	0.0108 "	0.355 "	0.2213 "	0.009 "	0.023 "	0.19 "
672A, ...	99.176 "	0.0114 "	0.366 "	0.2344 "	0.011 "	0.019 "	0.182 "
673A, ...	99.55 "	0.0049 "	0.1443 "	0.0608 "	0.008 "	0.011 "	0.22 "

Samples Nos. 664B, 665C, 666A and 673A are fairly good sands for all ordinary kinds of glass, and are often used for flint glass, but have to be corrected when thus used. Their chief use, however, is for window, green and amber glass. Sands like 671A and 672A are used only for the cheaper grades of glass where the color makes little difference, as in beer bottles. Sample No. 663 is a Pennsylvania sand which is used extensively by the New Jersey glass manufacturers for the best grades of flint glass.

In regard to these analysis, it is hardly necessary to point out that they show the composition of the sample analyzed, not necessarily the true average chemical composition of the whole deposit. While care was taken to select a fair sample, yet the

amount of sand exposed at any one time during the life of a pit is a very small proportion of the total, and there is no reason for believing that the sand may not vary slightly in chemical composition from place to place.

The whiteness of these sands, often relied upon as a test of their purity, is a very poor indication of the iron content. Sample No. 672A is equally as white in appearance as sample 666A, but the analysis given above shows the former contains more than three times as much iron as the latter. If the iron were present as ferric oxide coating the quartz grains, or as one of the bases in a clay which was attached to the grains, the color might be a guide to the iron content, but this is not the case. Under the microscope the quartz grains are seen to be clear and colorless, and are not stained by iron oxide. We have pointed out that the sand contains numerous dark-colored minerals, which were identified under the microscope as leucoxene (probably), rutile, ilemenite and sphene, their relative abundance being indicated by the above order. These are heavier than the quartz, and with slight shaking readily settle to the bottom of a sample. They are also of a somewhat uniform size and will pass an 80-mesh sieve. The amount of iron and titanium found by analysis is readily explained by the presence of these minerals in the sands, and one cannot question the conclusion that the iron content which is especially detrimental, is due solely to these minerals, particularly to the ilmenite. If, therefore, some method can be devised whereby they can be eliminated without too great expense and the loss of too large a proportion of the quartz sand, the value of the remainder will be greatly enhanced. By the present method of washing in use throughout the glass-sand field, no effort whatever is made to remove them. They have apparently been overlooked, or else little importance has been attached to them.

The presence of these heavier minerals in the sand makes it difficult to obtain a sample which is a fair average of the whole bank. There was more or less concentration of them during the deposition of the beds, so that the composition of the sand varies from place to place. During transportation, the jarring of a loaded car, particularly if the sand be dry, is sufficient to cause considerable concentration of the heavier minerals toward the

bottom. Under these circumstances a sample taken from the top of a load may fail to represent the correct composition of the sand. If the sand is wet, this concentration during transportation does not occur, at least to so great an extent.

The iron imparts a green color to the glass, an effect which the manufacturer sometimes attempts to neutralize by the addition of manganese dioxide. Since, however, an excess of manganese gives a pink color, the importance of an accurate determination of the iron content is manifest. When the iron content of the sand is fairly uniform, this is comparatively easy, but when this is not the case the iron value of the sand must be constantly checked by chemical analysis. We have been informed by one of the glass manufacturers that this variation of the iron content was one of the greatest objections to New Jersey sands for flint glass. No two carloads were apparently the same, and sometimes the sand in different parts of the same car varied considerably. These facts may be due in part to the concentration of these heavy minerals in certain parts of the bank during deposition and in part to the concentration of these minerals in the bottom of the car during transportation.

Elimination of the iron.—The fact that the minerals containing the iron will nearly all pass an 80-mesh sieve, at once suggests the possibility of cleansing the sands by sieving. This was done in the laboratory with two dry samples, numbers 669A and 672A. Convenient quantities of these two sands were thoroughly shaken in an 80-mesh sieve, and then the iron, titanium and alumina in the part remaining on the sieve were determined and the results compared with the previous analysis, as shown below:

	Sample No. 669A.		*Sample No. 672A.*	
Constituents.	*Before Sieving.*	*After Sieving.*	*Before Sieving.*	*After Sieving.*
Fe_2O_3	0.0068	0.0022	0.0114	0.0029
TiO_2	0.117	0.024	0.234	0.0434
Al_2O_3	0.276	0.085	0.366	0.106

By this sieving process the amount of iron in the sample was reduced to one-third or less, of titanium to one-fifth, and of alumina to one-third or less. The lime and magnesia being so

low in the original samples, were not determined in the sieved portions. These sands, which previous to sieving were only second-grade sands on account of their iron, were by this means rendered suitable for the manufacture of the best grades of flint and plate glass, the iron content being as low as in sample No. 663 which is used for this purpose. The samples thus treated compare very favorably with the sands used by the Pittsburg Plate Glass and the American Window Glass Companies, as shown by the following analysis:

Analysis of sand used by the Pittsburg Plate Glass Co.[1]

Constituents.	*No. 1.*	*No. 2.*	*No. 3.*	*No. 4.*
Silica (SiO_2),	99.21	98.90	98.95	98.94
Alumina (Al_2O_3),	.30	.20	.50	.30
Volatile matter,	.21	.25	.24	.23
Iron oxide (Fe_2O_3),	.003	.002	.0024	.0036
Lime (CaO),	.20	.54	.30	.40
Magnesia (MgO),	trace	.20	.10	trace
	99.923	100.092	100.0924	99.8736

When sands of the above composition are used no correction for color is attempted in manufacturing plate glass.

Analysis of sand used by American Window Glass Co.[2]

Constituents.	*No. 1.*	*No. 2.*	*No. 3.*	*No. 4.*
Silica (SiO_2),	99.99	99.714	99.659	99.579
Alumina (Al_2O_3),	.008	.280	.310	.350
Iron oxide (Fe_2O_3),	slight trace	.006	.011	.021
Lime & magnesia (CaO & MgO),	.002	.020	.020	.050
	100.00	100.00	100.00	100.00

It is to be noted further that our sieving removed not only a large percentage of the objectionable minerals, but it also re-

[1] U. S. Geological Survey, Bulletin No. 285.

[2] It is to be noted that no water determination appears in these analyses, and the silica is taken by difference. Consequently, the silica is just as much too high as the amount of water carried by the sand. Taken from U. S. Geological Survey, Bulletin No. 285.

moved all the fine grains under 80-mesh size. Reference to the tables of physical tests on p. 88 shows that in five of the eight samples the part passing this sieve is 11 per cent. or less of the whole; in three cases it is considerably more. The elimination of these finer grains would make the sand more desirable from a physical standpoint, and probably add something to its value. The Pennsylvania sand, No. 633, contains less than 2 per cent of grains finer than an 80-mesh, and it is also low in iron. Large amounts of it are imported by New Jersey glass manufacturers annually at a cost of about $3.00 per ton. If by sieving, the New Jersey sands can be raised, both chemically and physically, to the grade of this Pennsylvania sand, and enhanced in value from 90 cents to $3.00 per ton thereby, the problem is worth careful consideration by glass producers.

We have indicated that on the average from 10 to 15 per cent. of sand grains, practically all including the iron-bearing minerals, passed the 80-mesh sieve. This fine-grained sand would therefore be valueless for glass purposes, but it might not all be a loss, since sand grains of this size are always sharp and angular and so will cut much faster than rounded grains. There might be, therefore, a market for it as grinding material. But even if there were not, the New Jersey sand producer could well afford to sacrifice 20 per cent. of his product if the remaining 80 per cent. could be cheaply raised to the grade of the high-priced sand imported from Pennsylvania.

We are aware that it is one thing to sieve thoroughly a small quantity of dry sand in a laboratory and eliminate the finest grains and the iron minerals, and quite another thing to treat wet sand effectively and cheaply on a commercial scale and in large amounts. We have hopes, however, that the inventive genius of the sand producers may make some use of this suggestion. We do not need to emphasize the importance to the industry of improving the grade of sand if it can be done cheaply.

It is not claimed that the size of the screen used in these experiments is the one that would always give the most satisfactory results in actual practice. These impurities vary in size in different deposits, so that a screen of another mesh might be needed in some localities to get the best results.

If it be found impossible in practice to remove these grains by washing or sieving, there remains the question of magnetic separation, which has worked so successfully in late years with various kinds of ore.

Ilmenite and magnetite are both magnetic, as are many other iron-bearing minerals, and in a dry sand can very probably be concentrated by the magnet. Whether the process would be successful with the wet sand as it comes from the pits and washeries, and whether it could be economically carried out, are questions which we cannot enter upon here.

Production.—As a producer, New Jersey is surpassed by five States in the amount of glass sand produced, and by only four States in value of the product. While the West Virginia and Pennsylvania producers get on the average $1.50 and $1.31 at the mines, respectively, per ton for their product compared with 80 to 90 cents in New Jersey, the former deposits are much more expensive to operate than the latter. The Illinois and Missouri producers, however, get only about 60 cents per ton.

During the summer of 1906, the following firms were digging glass sands:

Pit No.	*Owner.*	*Location of Pit.*
661	Crystal Sand Co.,	Maurice River below Millville.
662	Crystal Sand Co.,	Cedarville.
664	R. O. Bidwell,	South Vineland.
665	John Burns,	South Vineland.
666	Crystal Sand Co.,	North Pit, South Vineland.
667	Crystal Sand Co.,	South Pit, South Vineland.
668	S. W. Downer,	Downer.
669	Weirick & Fields,	Radix.
670	Reakirt Glass Sand Mining Co.,	Sicklerville.
671	A. L. Thomas,	Tansborough.
672	Reading Sand Co.,	Penbryn.
673	Wm. Ranagan,	South Vineland.
	McCoys,	South Vineland.
	Appleby Sand & Clay Co.,	Old Bridge.
	Henry Wagner,	
	Asa Redrow,	

A table showing the amount of glass sand mined in 1905 in the different States and value of the same is given below, based on statistics published by the United States Geological Survey.

	Short tons.	Value.
Pennsylvania,	361,829	$482,937
Illinois,	234,391	146,605
West Virginia,	155,052	225,734
Missouri,	123,467	66,401
Ohio,	74,460	79,999
New Jersey,[1]	35,673	30,005
Maryland,	17,899	20,108
California,	9,257	8,112
Massachusetts,	4,600	12,000
Georgia,	4,500	4,050
New York,	3,165	3,115

Summarizing the principle facts regarding the glass-sand deposits of New Jersey, which have been discussed more or less in detail above, they may be said to be chiefly these:

1st. The supply of glass sand is sufficient to meet the demands of the glass industry for an indefinite period.

2d. There are apparently numerous undeveloped deposits adjacent the present railroad lines.

3d. The chances of finding good deposits in localities remote from the present railroads are equally as good as in localities adjacent thereto, but without cheap transportation they cannot be utilized at present prices.

4th. The deposits are of fairly good size and can be developed at a low initial cost compared with the deposits of Pennsylvania and the Middle West.

5th. The physical character of the sand equals, if it does not exceed, that of the western fields.

6th. The sand as mined to-day is well suited for the manufacture of green, amber and window glass.

7th. By the elimination of the iron-bearing minerals, either by sieving, improved methods of washing or perhaps by magnetic separation, the New Jersey product can probably be made suitable for the manufacture of flint and plate glass.

8th. They are well located regarding shipping facilities and the markets of the large cities of the East.

April 2, 1907.

[1] Figures obtained by the State Survey indicate that the above production for New Jersey is far below the actual product. Twenty glass manufacturers within the State report using 50,692 tons of New Jersey glass sand for year ending June 30, 1906. The total actual production in 1906 was probably over 100,000 tons.

PART III.

The Origin and Relations of the Newark Rocks.

The Newark (Triassic) Copper Ores of New Jersey.

Properties of Trap Rocks for Road Construction.

By J. VOLNEY LEWIS.

The Origin and Relations of the Newark Rocks.

BY J. VOLNEY LEWIS.

CONTENTS.

INTRODUCTION.

Extent of the Newark System.

The Newark (or Triassic) system of New Jersey (Pl. XXVIII) is part of a long, narrow belt extending from southern

New York southwestward across New Jersey, Pennsylvania, Maryland, and northern Virginia, as shown on the outline map, Fig. 1, and this is but one of several similar disconnected areas in the Atlantic coastal region from Nova Scotia to South Carolina. The belt across New Jersey occupies about one-sixth of the total area of the State, extending from the Hudson River and the New York State boundary to the Delaware River. It comprises the Piedmont region, which is intermediate in elevation

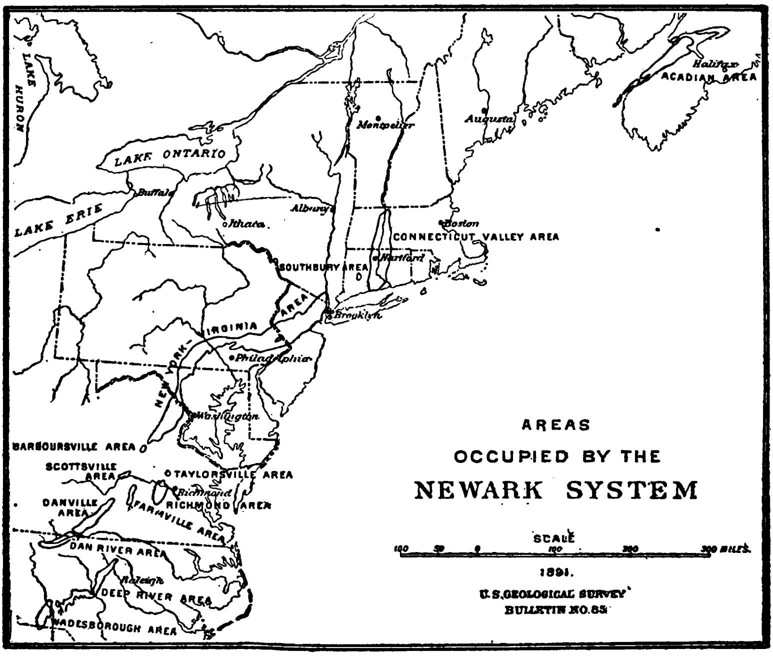


Fig. 1.

and surface features between the low, smooth Coastal Plain to the southeast and the higher and more mountainous Highlands to the northwest. Its undulating surface is interrupted by several conspicuous ridges, notably the Watchung Mountains and the Palisades in the northeast and Cushetunk, Round and Sourland mountains and Rocky Hill in the southwest.

The rocks of this system have been fully described in the previous reports of this Survey, particularly by Kümmel[1] about a

[1]Annual Reports of the State Geologist for 1896, pp. 25–88; 1897, pp. 23–159.

decade ago. In connection with recent studies of the petrography of the trap rocks and the occurrence and origin of the copper ores, however, some conclusions have been reached which are at variance with views heretofore published, and these are set forth in the following pages.

Characters of the Sedimentary Rocks.

The sedimentary rocks of the Newark system, as is generally known, are chiefly fine-grained red shales, with some sandstones and conglomorates (Brunswick), and, at some horizons, thick black argillites which do not readily split into thin layers (Lockatong). Coarse conglomerates occur not only near the base of the series, but also near the top and at various intermediate horizons. Heavy-bedded sandstone also occurs at various levels, chiefly, but not exculsively, in the lower part (Stockton). Associated with the black argillites are gray and green flagstones, and occasionally thin layers of very calcareous shale; but the great mass of the formation in its most characteristic phase is a soft red shale, in which occasional layers of purple, green, yellow and black shales occur.

"Ripple-marks, mud-cracks and raindrop impressions occur at many horizons. In some quarries impressions of leaves and stems of trees, or the stems themselves, are not infrequently found. Occasionally slabs are found bearing the foot-prints of reptiles and other vertebrates which wandered over the soft mud-flats while these beds were in process of accumulation." [1] Cross-bedding, or plunge-and-flow structure, and rapid variations of texture in the individual beds are also common characteristics of the coarser sediments.

Sources of the Sediments.

Many of the sandstones, particularly the coarser ones, are feldspathic and have numerous flakes of mica, all of which are

[1] Kümmel, Ann. Rep. of State Geologist, 1897, p. 42.

products of the disintegration of granites and gneisses, with little decomposition. The conglomerates sometimes contain gneissic pebbles, but most of them are composed of fragments broken from Paleozoic quartzites and limestones. The purer sands are doubtless residual grains from decomposing granites and gneisses and from crumbling quartzites. The shales are consolidated mud-beds, derived from residual soil of limestones and from the decomposing feldspars of granites and gneisses. All of these materials were washed down from the adjacent Highlands, the disintegration and decay of the underlying rocks renewing the soil as it was gradually removed by erosion and carried away by the streams.

It is not necessary to suppose that the lands were covered with an unusual thickness of such materials, for the period of deposition was of vast duration. We need only recall how slowly such sediments are accumulating in bays, lakes and flood-plains of rivers at the present time in order to form some conception of the immense periods of time represented by the Newark strata, which are probably more than two miles thick. We must further recognize the probability that there were long intervals during which deposition was retarded or possibly suspended altogether. The renewal of the soil keeps pace with the ordinary rate of erosion in hills and mountains of moderate slope, but the conglomerates of the Newark show that mountain torrents often rent the solid bed-rocks asunder and contributed their fragments in the forms of pebbles and bowlders to the accumulating sediments.

ORIGIN OF THE SEDIMENTS.

In considering the question of origin, it is necessary to bear in mind the distribution of the Newark rocks in adjoining regions along the Atlantic coast, as shown in Fig. 1, and particularly to note that this belt in New Jersey is part of a long strip that skirts along the region of the crystalline Highlands from Haverstraw, New York, southwestward through New Jersey, Pennsylvania, Maryland, and far into Virginia. This is the most ex-

tensive single area, but the others are much like it in form and characters of sediments.

The Tidal Estuary Hypothesis.

It has long been customary for geologists to speak of the Newark beds as having been deposited in "broad, shallow estuaries, whose shores were laid bare by the retreating tide, and in which the varying currents alternately deposited coarse and fine materials." The ripple-marks, sun-cracks, raindrop impressions, and tracks of animals were regarded as proof that the strata were once low beaches or mud-flats, laid bare at low tide, where land animals came in search of food.[1] "At the beginning of Newark time, therefore, we must conceive of a broad, shallow estuary extending across the northern part of what is now the State of New Jersey. * * * The streams from the bordering land areas carried into the estuary rock debris which was distributed over the bottom by the waves and tidal currents. The waves beating against the shore contributed their quota of material. * * * The sudden alternation from shale to conglomerates, the rapid thinning out of individual layers, the presence of ripple-marks, raindrop impressions and mud-cracks indicate that these beds were formed in close proximity to the shore line. Sticks and trunks of trees were frequently imbedded in the layers of sand and gravel. These deposits were formed quite widely over the floor of the estuary, *near the middle as well as near the present border,* since the Hopewell and Flemington faults bring similar beds to the surface." * * *

"Frequent mention has been made of the fact that the Newark beds are shallow-water deposits throughout their entire thickness. At no time, apparently, was the water of the estuary so deep that the outgoing tide did not expose broad areas of sand or mud. It follows from this that there must have been a progressive subsidence in the estuary during the deposition of these

[1] Kümmel, Ann. Rep. of State Geologist, 1897, p. 139; Newberry, Mon. U. S. Geol. Sur., XIV, 1888, p. 5; Russell, Bull. U. S. Geol. Sur. No. 85, p. 45.

beds, since their thickness is to be measured by thousands of feet. The subsidence went on *pari passu* with the deposition of the sediments, so that the *shallow water conditions prevailed continually*." [1]

This interpretation was regarded as satisfactory by geologists generally less than a decade ago, and it is still to be found in the current text-books.

The Lake Basin Hypothesis.

In connection with the estuary hypothesis described above, or as an alternative to it, the supposition that some areas of Newark rocks were formed in lakes has been advocated. The gradual subsidence is assumed in this case, as in that of estuaries, and the concurrent filling up by sediments so as to maintain a constant alternation of shallow water and bare mud and sand flats. Otherwise the conditions of the lake hypothesis are identical with those stated above.

Objections to the Foregoing Hypotheses.

It is now beginning to be realized (1) that impressions made on soft muds or sands at low tide are effaced by the next succeeding high tide or are preserved only under exceptional conditions; (2) that the features once ascribed only to tidal shore, or littoral, deposits are much more characteristic of alluvial sediments on land; and (3), finally, that the area of such littoral deposits is much smaller than that of river-made deposits above tide, and that they should consequently be comparatively rare in the sedimentary records of the past.[2] It is seen also that the current hypotheses offer no satisfactory explanation of the alternation of coarse sands and gravel with layers of fine mud near the middle as well as along the shores of the estuary or lake.

Furthermore, the *pari passu* subsidence, keeping pace with the rate of deposition, which must be assumed in order to provide

[1] Kümmel, loc. cit., pp. 139–143. The italics are not used in the original.

[2] Relative geological importance of continental, littoral and marine sedimentation. Joseph Barrell, Jour. Geol., XIV, 1906, pp. 316, 430, 524.

continuous shallow water conditions, is highly improbable when extended over the immense period of time necessary for the accumulation of sediments many thousands of feet thick. The entire absence of marine fossils is inconsistent with the estuary hypothesis, while the presence of land plants and animals, with only occasional fresh-water forms, is quite unfavorable to any extensive application of the lake hypothesis.

These difficulties were fully realized by Professor J. D. Dana, who says: "It is not possible that the sandstone formation was made during a general submergence and in a great common body of water; for there is nothing marine about it in fossils or in structure; and fresh waters for the work could not have spread over the region of hills, ridges, and valleys under any probable circumstances."

The Hypothesis of Orographic Valleys.

Professor Dana points to the facts that the Nova Scotia and Connecticut Valley belts of these rocks lie in the same troughs that had received sediments through a large part of Paleozoic time, and, further, that "the parallelism of the belts to the mountain ranges of the continental border is close,, * * * as if occupying orographic valleys of the Appalachian mountain chain." These orographic valleys he conceives to have been occupied by great broad rivers that made "conglomerates where the water had great velocity, sandstones in gentler currents, shales in the sluggish waters, and beds of vegetable debris for a coal bed where the conditions were those of a great marsh."* * *

"Where were the sources and what the directions of the rivers over the higher lands from New York to North Carolina, which supplied so generally granitic sediments instead of quartzose sands and fine clays, are questions not easily answered." * * *

"The river or waters of the time flowing southward, just west of the site of New York City—where now flows the Hudson—were 25 miles wide, as the breadth of the Triassic of the region shows, and they had sources evidently in the nearer mountains to the north, west, and south. These sources were probably in the Highlands and other ridges of crystalline rocks. The waters

and sediment certainly did not come from the Catskill Mountains to the north nor from the Alleghanies to the west."[1]

Objections to the Orographic Valley hypothesis.

The width of Newark strata opposite New York city is only an unknown fraction of their former extent, for the northwestern border is here determined by a fault, the Cretaceous overlaps on the southeast, and the monoclinal structure of the remainder shows that vast amounts have been removed by erosion. Assuming flood-plains of such proportions it is not remarkable that the sources and directions of the rivers by which they were formed should present difficult questions. The difficulty is vastly increased by the fact that the drainage of the Catskills and the Appalachian Mountains passed off in other directions, since the Newark sediments were derived from the older crystallines.

A Piedmont Plain hypothesis.

Four prominent conditions are to be considered in discussing the origin of the Newark sediments of New Jersey and the Atlantic region generally; namely (1) the evident derivation of most of the material from regions of crystalline rocks; (2) the strongly marked evidences of deposition by rivers, with only local lakes, and possibly estuaries; (3) the occurrence of these rocks in well-defined, long, narrow, basin-like areas parallel to the main structural lines of the Appalachian Mountains; (4) the wide-spread occurrence of fossil land plants and footprints of land animals, with bituminous shales in many localities and coal beds in Virginia and North Carolina, in contrast with the limited local areas of fossil fishes and crustaceans, which may be either brackish or fresh-water forms.

These conditions are believed to be fully met by the hypothesis of river deposition across a relatively smooth piedmont plain

[1] Manual of Geology, 4th ed., 1895, p. 743.

fronting the newly uplifted crystalline foreland, or protaxis, of the Appalachian Mountains, with concurrent synclinal wrinkling and down-faulting of the long basin-like areas in which the present remnants of these rocks have been preserved.

During the Appalachian uplift and for long periods afterwards the crystalline protaxis must have remained the great divide between the waters of the Gulf drainage and those that passed directly into the open Atlantic. Numerous short but vigorous streams brought down the debris of the disintegrating and decomposing granites, gneisses, and metamorphic sediments of earlier Paleozoic age, and deposited them in coalescing alluvial fans across the smoother plain of the crystalline Piedmont. Occasional downward movements, of warping or faulting, gave opportunity for local thickening of the deposits along the belts affected.

According to this conception the Piedmont plain was of much greater width than the present areas of the Newark strata, and it probably merged into coastal marine and estuarine deposits along the eastern border. As a rule, however, the deposits were probably not very thick except in the elongated areas of progressive or intermittent deformation. Hence when the whole Piedmont was eventually uplifted the relatively thin mantle of debris was removed by erosion from the greater part of the region, and only those narrow belts that were protected by down-warping and faulting between adjacent areas of the harder crystalline rocks have been preserved to the present time.

The northwestward tilting caused the displaced strata to be beveled off across the upturned edges and brought up again the crystallines along the southeastern border. These crystallines form the hills that everywhere skirt the eastern boundary of the New York-Virginia area except where it crosses New Jersey, and similar conditions are found in the various other belts of these rocks along the Atlantic slope. Across the narrowest part of New Jersey, however, these eastern crystallines were again so greatly worn down and depressed that they were buried by the later Cretaceous sediments, except a small area of gneisses now found in the vicinity of Trenton. On account of these over-

lapping Cretaceous sands and clays, the exact southeastern limit of the Newark formation from Trenton to Staten Island is not known.

The generally scant vegetation and the highly oxidized, iron-stained sediments that prevail in the Newark strata strongly suggest an arid climate. In this case the deposition of the sediments was perhaps as much due to loss of volume as to change of slope in the contributing streams, as in the arid piedmont plains of southern California and elsewhere in the western United States to-day.

Late in the period of deposition of the Newark strata continued depression of the elongated narrow belts along the Piedmont plain, by folding and faulting, eventually gave rise to fissures through which repeated eruptions of lava overspread considerable areas of the deposits and great intrusive sheets, or sills, of similar lava were injected between some of the deeply buried strata.

GEOLOGIC RELATIONS OF THE TRAP ROCKS.

The distribution of the trap rocks, which constitute more than one-tenth of the total Newark area of the State, is shown on the accompanying map, Pl. XXVIII. Davis, Darton, Kümmel and other workers in this field have shown that these rocks are of igneous origin and were formed during the latter part of Newark time. They represent both lavas that reached the surface and became *extrusive,* and also lavas that penetrated the sediments and became *intrusive.* Their geologic relations have been described in detail by Kümmel in a previous report of the Survey.[1] Supplementary to that report, attention is here directed to certain further correlations of the various trap masses and to some difference of interpretation of observed relations.

Relations of the Extrusives.

The Watchung flows.—The Watchung Mountains and the various trap ridges west of them are all extrusive sheets, or lava

[1] Ann. Rep. State Geologist of N. J. for 1897, pp. 58–99.

flows, as are also the semi-circular ridges near New Germantown and Sand Brook. The grouping of these sheets in the west-central portion of the area, where no intrusives occur, and their almost total absence from the areas of intrusives to the northeast and southwest are characteristics which are forcibly impressed by the map, Pl. XXVIII. The former is the area of uppermost and, therefore, latest Newark strata, while the deep-seated intrusive masses have been laid bare only where these later strata have been removed to great depths by erosion.

The thinning out of the lowest extrusive lava sheet north of Somerville apparently causes the narrowing down of First Mountain and its final termination at Pluckamin. Second Mountain recurves in hook form until cut diagonally across by the great boundary fault near Bernardsville. This fault continues northward to the State line and terminates the curved extremities of all three of the extrusive sheets beyond Pompton. The recurved ends of these ridges are the result of the Passaic Basin syncline, the shallow boat-like structure into which the strata and the trap sheets of this region have been bent.

Packanack and Hook mountains, Riker Hill and Long Hill, by their structure and attitude with reference to each other, are quite probably parts of a single extrusive sheet. As to their extrusive character there can be no question, and they are all much thinner than the great flows that constitute First and Second mountains. Their disconnected character may be explained upon the hypothesis that the eruption was slight and did not completely cover the area, so that there were tongues, or projecting lobes of lava, or there may have been several small eruptions from independent vents or fissures. On the other hand, their discontinuity may be due to preglacial or glacial erosion, the portions that were most worn down being buried by the later deposition of glacial drift and river sediment that now cover much of this region.

All of these hypotheses seem to be consistent with the facts so far as known, but further knowledge of the strata now buried beneath the broad alluvial flood-plains of the upper Passaic River may be necessary in order to determine which is the correct in-

terpretation. Under the circumstances, one of the hypotheses of scant eruption seems most probable.

The semi-circular trap ridge near New Vernon is a thin extrusive sheet exactly similar to that of Long Hill; and, in fact, it seems quite certainly to be the upturned western border of the same sheet. The structure of the shales within the trap ridge shows that it has been brought up by a dome-like anticline, or upward fold, which has thrown the outcrop far enough eastward to prevent its being cut off by the great fault along the adjacent border of the crystalline Highlands.

The Double Crest of Second Mountain.—The striking and persistent double crest of the curved southwestern part of Second Mountain (Fig. 2) has been explained[1] as the result of a curved longitudinal fault parallel to the present outcrop of the trap sheet. While entirely consistent with the facts so far as at present known, the probability of such a coincidence is so extremely small that, in the absence of positive proof of faulting, this hypothesis must be regarded as exceedingly doubtful. Brief discussions are here given of (1) the facts requiring explanation, (2) the interbedded shale hypothesis, (3) the curved longitudinal fault hypothesis, and (4) the hypothesis here advanced, namely, that of a double flow of lava with intercurrent warping. The last is somewhat more fully presented and its bearing upon subsequent geologic history discussed. The others are summarized from Kümmel's report, above cited.

(1) The facts requiring explanation.—The width of outcrop of the trap along Second Mountain varies greatly. The hook-shaped southwestern portion is broader than elsewhere, and for a distance of 17 miles the crest is distinctly double. In the intervening valley shale has been found in a number of places, either in well-borings or at the surface. At both ends of the ridge, however, the crest is single, and no shales are found interbedded in the trap in the gorge of the Passaic River at Little Falls. In a well at Mount St. Dominic Academy, at Caldwell, the following section was found: Glacial drift, 100 feet; trap

[1] Darton, Bull. U. S. Geol. Survey No. 67, p. 22. Kümmel, Ann. Rept. of State Geologist for 1897, p. 125.

rock, 775 feet; total 875 feet; shale at the bottom. A well bored for Mr. Keane on the inner crest of Second Mountain, near East Livingston, and 3 miles from the well at Caldwell, furnished

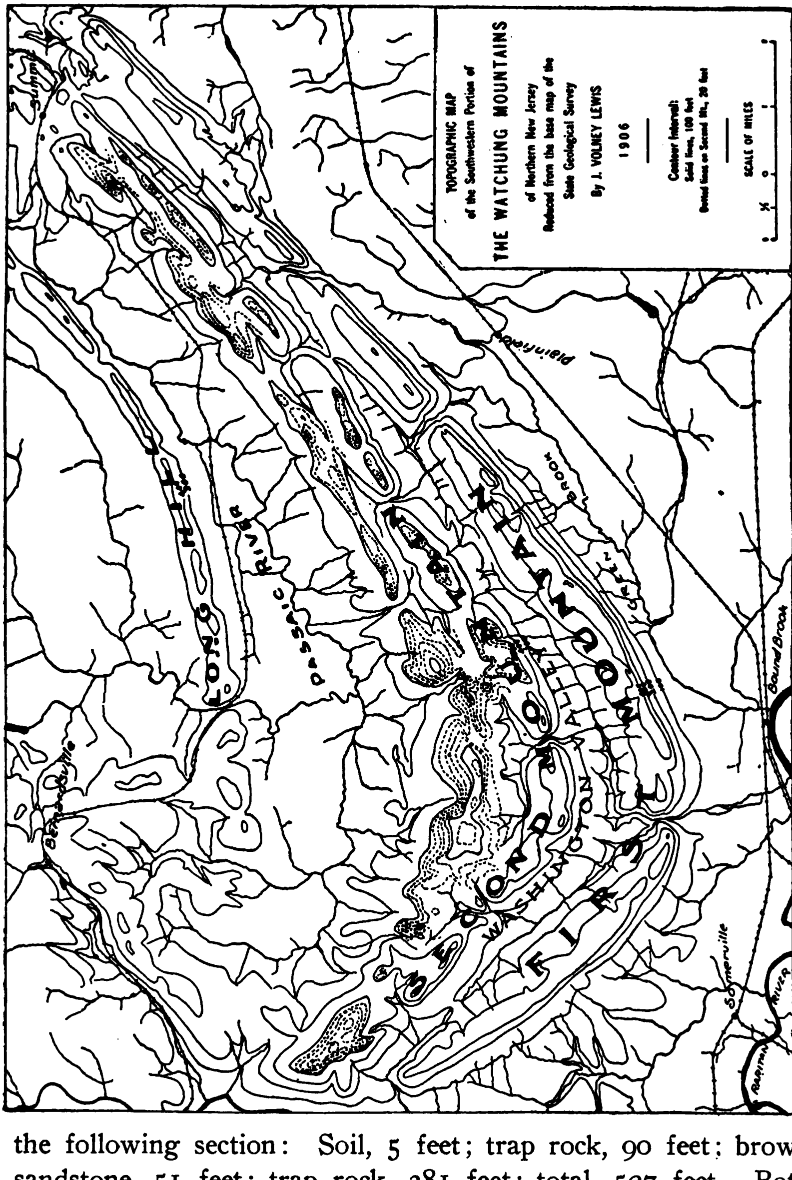


Fig. 2.

the following section: Soil, 5 feet; trap rock, 90 feet; brown sandstone, 51 feet; trap rock, 381 feet; total, 527 feet. Both wells are in such locations as to pass through an interbedded

layer of sediments, if such existed. Over the country between the two crests, Darton found red shale fragments, which he regarded as portions of underlying sediments.

(2) The interbedded shale hypothesis.—Kümmel considered the hypothesis that Second Mountain is composed of two successive flows of lava separated by a continuous stratum of sediments, but rejected it for the following reasons: (a) the crest is single at both ends of the ridge; (b) no trace of shale is found at either locality; (c) the Little Falls gorge and the Caldwell well show no shale. The "brown sandstone" reported from Mr. Keane's well he regards as probably a red-brown variety of trap.

(3) The fault hypothesis.—Under the apparent necessity of choosing between the interbedded shale hypothesis, described above, and that of a fault which conforms to the present outcrop around the sharply recurved southwestern extremity of Second Mountain, both Darton and Kümmel adopted the latter, in spite of the fact that "no direct evidence of faulting beyond that furnished by the topography—the repetition of the beds—was found." "Indirect evidence derived from a study of the width of the outcrop of the trap and the apparent thickness along different section lines," may be summarized as follows: On the assumptions (a) that there was no deformation in the intervals between the lava flows (nor accompanying the flows); (b) that sedimentation was uniform throughout the area; and (c) that the lava sheets are approximately of uniform thickness, their bases must have been originally parallel. Allowing for known faults this is still true of First and Second mountains; but from the base of the Second to that of the Third (Long Hill, etc.), is a distance that varies greatly in different sections, and the apparent differences are greater where the double crests of Second Mountain are most marked. This variation is ascribed to faulting, which Darton assumed further to be confined to the present areas of trap outcrop.

Kümmel points out several very obvious defects in the above reasoning: (1) that any or all of these various assumptions may be incorrect; (2) that there is no conclusive reason for supposing that faulting is restricted to the trap areas of the present

surface, and (3) that variations in thickness of either the trap of Second Mountain or of the overlying shales would vitiate the conclusions. Notwithstanding these elements of uncertainty and improbability, however, the estimates based on the above assumptions are regarded as "indicating quite clearly that some faulting has occurred," and as "strengthening the argument derived from the double crest." Hence the conclusion that "it is safe to assume that Second Mountain is traversed for much of its extent by a curving longitudinal fault."

(4) A hypothesis of double flow with intercurrent warping.—The explanation here advanced is believed to be consistent with all the known facts and to involve no improbable assumptions. It is practically the interbedded shale hypothesis, described above, freed from the restrictions of stability and uniform sedimentation in the intervals between the lava flows.

The present condition of the Newark rocks throughout eastern North America shows that they have been subjected to universal deformation, and as yet there is no known means of defining the exact stage in their history at which the disturbing movements began. The slightest warping of the surface at any stage of the sedimentation would have its inevitable effect on the thickness and distribution of the subsequent deposits. This is specially true of shallow water and continental formations, such as these Newark beds are generally conceded to be.

The proposed hypothesis to account for the conditions above enumerated in Second Mountain may be stated as follows: After the eruption of the First Mountain trap sheet and the deposition of some 600 feet of overlying shales and sandstones, a second eruption occurred, forming a lava sheet averaging probably 500 feet thick over the same region. With this outflow began a gradual depression of the southern axial region of the Passaic Basin syncline—the region from Somerville northeastward. As a result subsequent deposits were concentrated in this region, tending to build it up to the level of the adjoining area, but not succeeding entirely in this before deposition was again interrupted by eruption. Another lava sheet of about 500 feet average thickness was spread over the region, but not uniformly, nor even

approximately so, as the preceding flow had been. Over the shales in the depressed area the maximum thickness was at least 800 feet, while in the adjoining regions where it rested on the

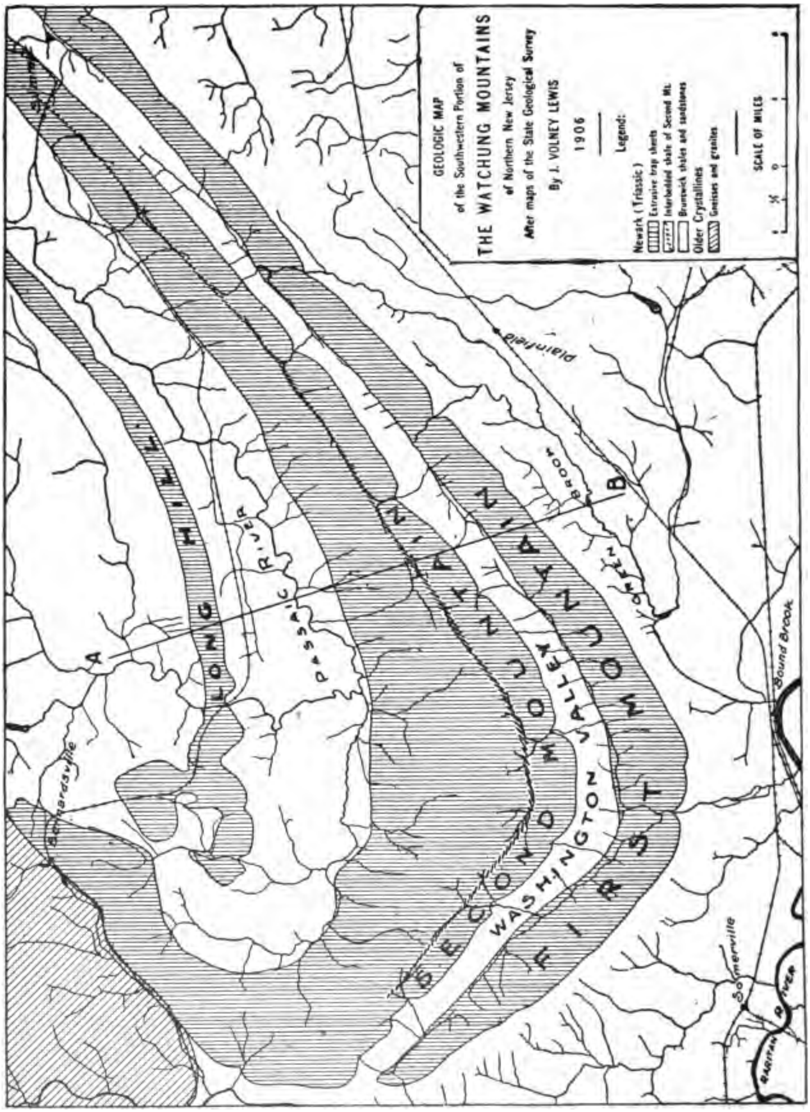


Fig. 3.

unburied flanks of the previous flow it did not exceed 200 feet. Thus the two flows merged into one on the sides of the incipient

syncline, but were separated by a thin stratum of shale in the depression. (Figs. 3 and 4).

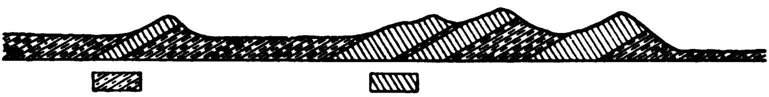


Fig. 4.

Sediments. Trap sheets.
Cross section on line A-B, figure 3.

When the edges were later upturned to the forces of weathering and erosion the soft shales quickly wore away to a lower level, thus forming the continuous valley curving conformably with the outcropping edges of the adjacent traps above and below. The valley between the double crests of Second Mountain is, therefore, considered to be exactly comparable to Washington Valley between First and Second mountains. It is shallower and the escarpment of the overlying trap outcrop is less pronounced because of the limited thickness of the interbedded shales. (Fig. 4).

Evidence of continued depression in the same synclinal region is found in the sediments between Second Mountain and the overlying trap sheet of Long Hilll. There is a decrease of one-fourth in the thickness of the intervening shales at Madison as compared with those at Millington, and a much more rapid thinning out toward the west. The trap sheet of Long Hill is also thicker about Millington, but this may not be due to original inequality of the surface upon which it was laid.

The Sand Brook and New Germantown Extrusives.—These two small areas deserve special notice, because they have preserved remnants of trap sheets that were doubtless once much more extensive. Each is but the eastern spoon-shaped end of a syncline that has been cut off by a fault to the west, and each contains remnants of two separate masses of trap of exactly similar forms and relations. The larger mass in each case outcrops in a westward-pointing crescent and curves downward beneath the shales within. The smaller caps a rounded hill between the points of the crescent, thus resting upon the sediments that overlie

the synclinal sheet below.[1] At New Germantown this upper fragment is separated, doubtless by erosion, into two small disconnected masses.

Here we have remnants of two lava flows, separated by several hundred feet of shales, in exactly the same manner as the sheets of the Watchung Mountains. Kümmel[2] has shown, from the structure of the region, that they are "in a general way contemporaneous with the Watchung flows," but concludes that "there is no evidence that they are parts of the same flows." It may also be stated, on the other hand, that there is no evidence that they represent separate flows, and it may be shown that they probably do not. The lava sheets whose eroded edges form First and Second mountains, are certainly only remnants of the original flows, yet they still occupy a region about 12 by 40 miles in extent. Considering their great thickness in the vicinity of Bound Brook and Somerville, it is altogether probable that they once extended half as far again to the southwest, which would carry them beyond the most distant remnants at Sand Brook. In this case remnants of the eroded Watchung sheets, if of earlier origin, would now underlie those of New Germantown and Sand Brook, and would outcrop in larger curves to the east of these localities. On the other hand, unless these small remnants are parts of very limited local flows, they would also have overlapped the present area of the Watchung sheets. This is especially true of the New Germantown trap, which is only 6 miles distant. In this case their edges would appear in the shales beneath and southeast of the Watchung ridges, if older, or above, in the Passaic Basin syncline, if younger.

Since it is clear, then, from the stratigraphy of the region, that the New Germantown and Sand Brook traps are approximately

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[1] Kümmel, finding the contacts of these small inner trap masses so obscured by soil-covering at both localities that their relations to the sediments could not be observed, did not commit himself as to their extrusive or intrusive character. (Ann. Rep. of State Geologist of N. J., 1896, 1897.) The absence of metamorphism in the shales was noted, however, and the trap is quite vesicular, so that there can be little doubt that the interpretation given above is correct.

[2] Ann. Report of State Geologist of N. J., 1897, p. 98.

contemporaneous with the Watchung flows, the conclusion is almost imperative either (1) that they are exactly contemporaneous and parts of the same sheets, or (2) that the present remnants are fragments of small local outpourings of earlier date than the Watchung flows. Of these the former conclusion seems the more probable, and on this basis the New Germantown and Sand Brook traps are correlated with the trap sheets of First and Second mountains.

It should not be overlooked, however, that there is still another possible interpretation, namely, that neither the New Germantown and Sand Brook traps, on the one hand, nor the trap sheets of the Watchungs, on the other, have ever extended far enough beyond their present boundaries to overlap the regions now occupied by the other. In this case their relationships can be established only by the stratigraphy; and it is impossible, in the homogeneous red Brunswick shales of this region, to attain more than an approximate correlation, as quoted above from Kümmel. Even in this case, however, it is more probable, *a priori,* that the smaller eruptions took place contemporaneously with the greater volcanic activity in the adjacent area than at other times.

Relations of the Intrusives.

The sills, or intrusive sheets, include the Palisades to the northeast, along the Hudson River, and the trap ridges of Rocky Hill and of Pennington, Baldpate, Sourland, and Cushetunk mountains in the southwestern part of the area. Other intrusive masses, often closely associated with these, are more of the nature of round bosses, such as Mount Gilboa and the Snake Hills, or in the form of thin dikes, like that which crosses the Millstone River west of New Brunswick, and numerous shorter ones in other localities.

The Palisades, Rocky Hill, Sourland Mountain, Byram.—Both the position and direction of the main outcrop of the Rocky Hill trap strongly suggest that it is a continuation of the Palisades sill, as pointed out by various former observers. Darton[1]

[1] Bull. U. S. Geol. Survey, No. 67, 1890, p. 39.

states that "the interval between the Staten Island outcrops and those at Lawrence Brook is mostly covered by Cretaceous clays, under which the Newark is known to extend for some distance, and it is possible that the trap continues southward and is similarly overlapped." A number of facts that have been gathered from deep-well borings and river dredging in the intervening territory now make it practically certain that this supposition is true. (See Pl. XXIX.)

On Staten Island, shallow wells show the continuation of the Palisades sill southward to the vicinity of Fresh Kills, opposite Carteret, New Jersey. Three wells at the car works near Carteret (*a*, Pl. XXIX), after passing through sand and clay 60 and 90 feet, respectively, struck hard rock that "dulled the drill in 15 minutes," and reported by the contractor as "evidently trap rock."[2] At Boynton Beach (*b*, Pl. XXIX), 3 miles southwestward, the following well-section was found:

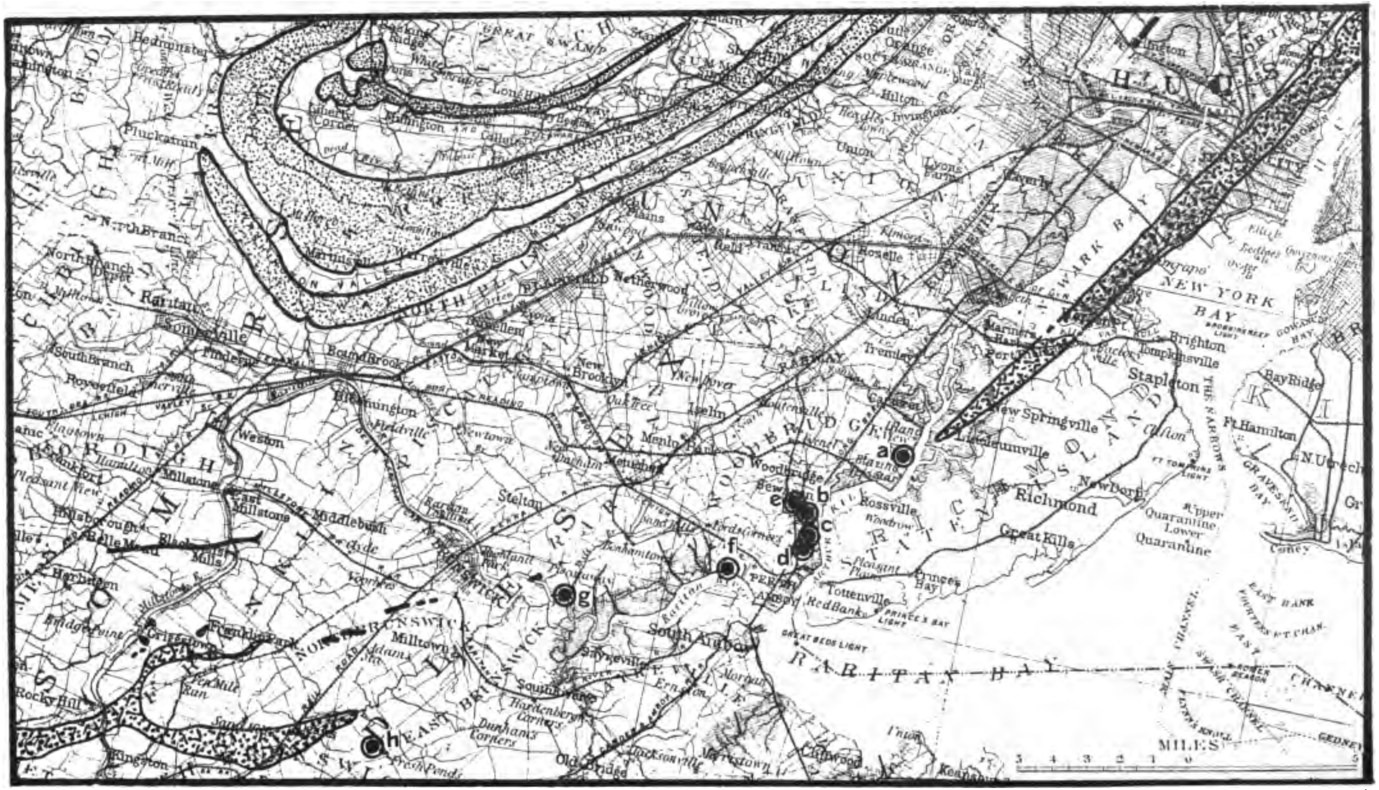
Clay, sand and gravel,	75	feet.
Red shale,	3	"
Trap rock,	70	"
Red sandstone,	2	"
Trap rock,	7	"
Total,	157	"

Evidently a sandstone inclusion in the trap was here encountered, similar to those found at numerous points northward along the Palisades.[3] Two wells bored at Maurer station (*c*, *d*, Pl. XXIX), 2 miles north of Perth Amboy, found trap under sand and clay 64 feet and 78 feet deep, respectively.[3] In a well drilled at M. D. Valentine & Brothers Company's works, three-fourths of a mile south of Woodbridge (*e*, Pl. XXIX), at a depth of 56 feet hard rock was found. At first this was supposed to be trap, but it afterwards proved to be indurated shale and sandstone. These are undoubtedly the metamorphic sediments over-

[2]Ann. Rep. State Geologist of N. J. for 1896, p. 199.

[3]Ann. Rep. State Geologist of N. J. for 1904, p. 265.

[3]Ann. Rep. State Geologist of N. J. for 1904, p. 268; 1895, p. 93.



Location of borings revealing trap (a, b, c, f, h), and baked shale (e, g), b etween the Palisade and Rocky Hill ridges.

lying the trap sill.[1] Near Keasby (*f*, Pl. XXIX), on the Raritan River, 2 miles west of Perth Amboy, hard rock, probably trap, was encountered under 72 feet of sand and clay.[2]

In dredging and blasting operations in the Raritan River, a mile below Martins Dock (*g*, Pl. XXIX), a reef of indurated shale 500 feet wide was found crossing the river in a northeast-southwest course, 5 to 12 feet below low water. No trap rock was found, but it cannot be doubted that this shale corresponds to the belt of metamorphic sediments everywhere skirting the great intrusive sills of trap.[3] Also 2 miles southeast of Deans station (*h*, Pl. XXIX), on the Pennsylvania Railroad, near Fresh Ponds, a bored well encountered trap rock under 60 feet of clay, unquestionably the buried margin of the Rocky Hill mass, which outcrops about Deans.[4]

Mr. W. R. Osborne, the contractor, also reports that trap was encountered in a bored well near the old Baptist church at South River, at a depth of 130 feet.

The trap dikes east, south and west of New Brunswick bear about the same relation to this buried extension of the Palisades sill as do those of the Snake Hills, Arlington, Granton and Bogota to its prominent outcrop farther northward. (Pls. XXVIII and XXIX.) As pointed out in the discussion of the copper ores, those of New Brunswick and Newtown occupy the same relative position with reference to this covered part of the sill that the ores of Arlington and Glen Ridge hold with regard to the Palisades.

The Palisades trap lies much lower in the sedimentary series than that of Rocky Hill, but the latter is highest at its western extremity and rapidly descends to lower horizons to the east, where it finally passes under the Cretaceous cover. A continued drop would readily unite it with the Palisades sill on Staten Island. Furthermore, the Rocky Hill trap increases in thickness

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[1]Ann. Rep. State Geologist of N. J. for 1895, p. 93. This locality was erroneously reported as 1¼ miles southwest of Woodbridge.

[2]Ann. Rep. State Geologist of N. J. for 1898, pp. 131, 132.

[3]Ann. Rep. State Geologist of N. J. for 1882, p. 59; 1895, p. 93.

[4]Ann. Rep. State Geologist of N. J. for 1900, p. 159.

eastward from its narrow outcrop near Hopewell, and the same thickening is continued in the Palisades sill northward from Staten Island and Bergen Point. As it passes further northward into New York the Palisades trap again becomes thinner, and its recurved extremity rises rapidly through the sediments west of Haverstraw until it reaches almost the top of the series. Their relations to the sediments are, therefore, entirely consistent with their continuity.

The intrusive trap masses of Pennington and Baldpate mountains are doubtless lobe-like protrusions of the same Palisades-Rocky Hill sill, as suggested by Darton, and all probably merge into one continuous sheet at no great depth. The irregular forms of Pennington and Baldpate mountains and the northeastward arm of Rocky Hill all indicate subterranean branching of the intrusive lava in this region.

The relations of the Sourland Mountain trap, brought up by the Hopewell fault in a repeated series of strata dipping northwestward, strongly suggest that it is also a part of the Palisades-Rocky Hill sill. (See section, Pl. XXVIII.). If depressed some 6,000 feet, the approximate throw of the fault, it would fall into line with the subterranean continuation of the trap of Rocky Hill, Pennington Mountain and Baldpate Mountain. In a similar manner Mount Gilboa, above Lambertville, and the smaller isolated trap mass at Byram, each lying on the upthrow side of a fault that repeats a portion of the sedimentary series, may reasonably be regarded as fragments of the same sill brought up from near its thinner northwestern border.

Thus, according to the view here advocated, the intrusive trap masses outcropping in the Palisades, in Rocky Hill, in Pennington, Baldpate and Sourland mountains, in Mount Gilboa, as well as the mass at Byram, are all to be regarded as probably parts of one continuous intrusion, separated by the Cretaceous overlap in the case of the Palisades and Rocky Hill, by lobe-like subterranean branching in Pennington and Baldpate mountains, and by faulting in the other cases.

There is a widespread impression that the Palisades sill drops steeply downward across the strata from its western margin, and geologists have generally so represented it in cross-sections. This

impression is doubtless due to the preponderating influence of three easily accessible upper contacts that do show such conditions for 20 or 30 feet. These are in the West Shore and N. Y. S. & W. Railroad tunnels through the Palisades, and the West Shore tunnel near Haverstraw. In two of these localities (the West Shore tunnels) both the topography and the boundaries of the trap outcrop show clearly that the relations are exceptional; but they have been emphasized by detailed descriptions and illustrations in the reports, while the conformable contacts have very naturally been passed over with a simple statement of the facts.

Kümmel[1] has described four conformable upper contacts, two unconformable, and two doubtful, while of the under contacts along the Hudson River only three are conformable, fifteen are unconformable, and one is doubtful. Yet, in spite of the numerous irregularities of the under surface of the trap, and its constant shifting from one horizon to another, it is evident that in a broad general view it is approximately conformable to the sedimentary strata. Even less irregularity is known in its upper surface, but probably, if an equal number of contacts could be observed, the conditions would be found about the same. At any rate, there seems to be no good reason why these upper contacts should be regarded as showing the fissure arising from the deep-seated origin of the lava, when it is perfectly clear that similar contacts beneath the Palisades are not susceptible of such interpretation.

Off-shoots of the Palisades Sill.—Snake Hill and Little Snake Hill are two knobs of trap which stand up prominently out of the Hackensack Meadows at distances of a mile and three-eighths and 1 mile, respectively, from the foot of the western slope of the Palisades. If the Palisades trap continues approximately conformable to the sedimentaries under the meadows, as it does along the Hudson River, it probably does not lie more than 1,600 feet and 1,300 feet, respectively, below the outcrops of the Snake Hills. These have, therefore, been very naturally regarded as off-shoots from it. In other words, they are less than one-fourth as far from the underlying sill as from its nearest outcrop, and it

[1]Ann. Rep. State Geologist for 1897, pp. 62–72.

would be difficult to construct a section on the basis of our present knowledge without connecting them with the Palisades.

The trap dike and sheet that form the small hill just north of Granton are about 800 feet from the nearest outcrop of the Palisades trap, but they cannot be more than 200 feet above the underlying portion of it. They must also be regarded, therefore, as an off-shoot from the Palisades.

The dikes and sheets at the Arlington copper mine are 4 miles from the Palisades at Jersey City and 6 miles from the trap of First Mountain at Montclair. Since the latter is a perfectly conformable sheet, dipping westward with the sedimentaries on which it rests, and the former is approximately conformable, with a similar dip, it seems probable that these dikes are also off-shoots of the Palisades sheet, which, with an average westerly dip of 12 degrees, would lie some 8,000 feet below.

In like manner the dike at Bogota, the numerous dikes east, south, and west of New Brunswick, and those scattered over the region northwest of Sourland Mountain are most readily explained as thin off-shoots from the same sill. In fact some of these in the last-named area have been traced by Kümmel to a direct connection with the great intrusive sheet at the outcrop, and there is little room to question that the others are of the same character.

Cushetunk and Round mountains.—The trap masses of Cushetunk Mountain and Round Mountain are intrusives of the same character as the great Palisades-Rocky Hill-Sourland Mountain sill, and may represent a contemporaneous upward protrusion of the same magna, but there is no means of definitely determining this question. There is, however, an interval of little more than 3 miles between Round Mountain and the dikes about Flemington, which are undoubtedly offshoots of the Sourland Mountain trap. Whether belonging to the same period of intrusion as these or not, it does not seem improbable that the upward movement of the magma was stopped and possibly its lateral extension determined by the overlying extrusives of the Watchung Mountains which have since been removed from this region by erosion. It is shown, in discussing the relations of the New Germantown and Sand Brook synclines, that the trap

sheets of First and Second mountains probably once extended over this region, and the known structures would carry them across just over Cushetunk Mountain.

The mutual relations of the various disconnected outcrops about Cushetunk and Round mountains are open to question. The structure is complicated and there are not sufficient outcrops of the sedimentary strata available in the vicinity of the trap masses to make satisfactory conclusions possible—not at least without considerably more minute and painstaking search over the area than it has yet been possible to make. Darton[1] concluded that all the masses in this vicinity had once probably constituted one wide intrusive sheet, "considerably flexed, and with the form of its present outcrops mainly determined by the removal of the trap from the crests of the anticlinals." Kümmel,[2] on the other hand, after thorough examination of the surrounding sedimentaries, concluded that the curving outline of Cushetunk Mountain "is not due, primarily, at least, to an anticlinal or synclinal fold in the shales, but to the curving fracture through which the trap has come." As to Round Mountain, he thought it probably intrusive, but did not regard the evidence as complete as in the case of Cushetunk Mountain. Metamorphic effects observed in the sediments on the slopes of the mountain in this investigation leave no doubt as to the intrusive character of the adjacent trap, and this is in harmony with its prevailingly coarse granitic texture. As to the relations of Round Mountain, the few facts observed seem to favor Darton's conclusion that it "lies in a well-defined synclinal or spoon, and is separated from Cushetunk by a local anticlinal" from which the trap has been removed by erosion.

Origin of the Trap Rocks.

The following statements in regard to their origin, while following in the main the conclusions of previous investigators, differ in some important details, particularly as regards the character of Second Mountain and the conditions of intrusion.

[1] Bulletin U. S. Geological Survey No. 67, p. 64.
[2] Annual Report of the State Geologist for 1897, p. 76.

Origin of the First Mountain Extrusive.

Eventually when weighed down under some 10,000 feet of clays and sands, in the New Jersey region, continued subsidence along the narrow belts of the Piedmont resulted in deep-seated fractures through which a great flood of lava was forced up. Breaking its way through the weak layers of the overlying sediments it spread in a broad sheet about 600 feet thick over the area of the present Watchung Mountains and beyond. How far beyond there is no present means of estimating. A remnant of this sheet remains, and its outcropping edge, now tilted up and worn by long erosion, forms First Mountain. Following this eruption, deposition and depression continued as before through a long period of quiet, during which the great lava sheet was buried under about 600 feet of additional sediments.

Origin of the Double Flow of Second Mountain.

Again the trough-like belt of depression was fissured and another flow of lava followed, forming a sheet of about 500 feet in average thickness.

The beginning of the great Passaic Basin syncline of the Watchung Mountain region probably dates from this period. The first gentle sagging was chiefly confined to the southeastern area of the Watchungs, in the region northeastward from Bound Brook. Consequently subsequent sediments were somewhat concentrated in this region tending to keep it graded up to the level of the surrounding area; but sedimentation was locally exceeded by depression, and possibly a lake was formed here, until the slow and gradual processes of deposition were again violently interrupted by eruption. Upon the thin blanket of sediment, perhaps less than 50 feet thick in the synclinal axis, and over the adjoining bare areas of the preceding flow, another lava sheet was spread with an average thickness of about 500 feet. Unlike the preceding flows, this was not even approximately uniform in thickness. In the more depressed synclinal area the

maximum thickness was at least 800 feet, while on the flanking bare areas of the preceding flow it did not exceed 200 feet. Thus the great double sheet of trap, now tilted up and outcropping in Second Mountain, is separated by a thin deposit of shale in the synclinal axis; hence the notable double crest around its curved southwestern extremity.[1]

Continued gentle sagging of the newly formed Passaic Basin syncline again caused increased thickness of the overwashed sediment in the central areas during the long period of quiet deposition that followed.

Origin of the Long Hill Extrusive.

The great double sheet of Second Mountain was buried beneath 1,500 to 2,000 feet of mud, when occurred the fourth, and, so far as the records preserved to us show, the last interruption of quiet deposition by renewed igneous activity. This final outpouring was small as contrasted with the enormous flows that preceded it. Its average thickness was probably not over 300 feet, and it apparently did not completely cover the area within the present basin of the upper Passaic River. Its irregular lobes may account for the present disconnected outcrops about New Vernon, and in Long Hill, Riker Hill, Hook and Packanack mountains. On the other hand, these may be the result of small local lava flows through several independent vents.

Finally the red shales overlying this last trap sheet, and now underlying the glacial drift and the recent river and meadow accumulations of the upper Passaic Basin, were gradually deposited in the uneventful period that followed the last volcanic outburst.

Origin of the Intrusive Trap Masses.

As to Kümmel's conclusion that the great intrusive traps were formed late in Newark time there can be no question, since several of the masses penetrate rocks that lie far above the middle of

[1] This double crest of Second Mountain has heretofore been explained upon the hypothesis of a "curved longitudinal fault." A discussion of this hypothesis will be found on page 112.

the series. He further states[1] that "there are good reasons for believing that many, probably all, of the intrusive sheets are younger than the extrusive, although the evidence is not conclusive," and suggests that intrusive sheets may have been formed only after the overlying sediments became so thick that the lava could not readily rise to the surface. According to any theory of deposition, however, the elevation of the surface did not vary greatly during the whole of Newark time. The force necessary to lift the lava to the surface would be little greater, therefore, at the close of deposition than at the beginning.

It is quite probable, however, that many of the deeper-lying strata had become appreciably consolidated by the close of the period, and that the several extrusive lava sheets now included in the series formed an additional barrier against further eruption. But inherent in the nature of the rocks themselves there was also a strong tendency to intrusion. The specific gravity of the trap averages about 3.0, while that of the sediments is approximately 2.5. Thus for every hundred feet in height of a column of lava there is an excess pressure of about 20 pounds per square inch over that of the inclosing strata. In case of such lava forced to the surface through 12,000 feet of sediments, the difference in pressure is 2,400 pounds per square inch at the bottom of the series. This is the measure of the tendency to intrusion. A standing column of such material, if it could be maintained in a liquid state would all find its way into the lower strata, lifting the overlying beds upon its surface. A gentle welling up of lava under such conditions, if it ever occurred, would necessarily result chiefly in intrusive masses. The overflow, then, is roughly a measure of the force of eruption in excess of that required merely to lift the lava to the surface.

Since cohesion in unmetamorphosed strata is always less along the bedding-planes than across them, solidification, in whatever degree, would also favor intrusion, unless the eruption followed a previously formed fissure. In the latter case the reverse would be true. The progressive consolidation of the sediments, therefore, and the resistance of the great lava sheets already imbedded

[1] Ann. Report of State Geologist of New Jersey 1897, p. 99.

in the upper strata would furnish predisposing conditions which might divert an eruption of considerable violence into subterranean channels. Hence it is altogether probable that the principal intrusive bodies were formed after the surface flows, and possibly in the early stages of those disturbances that put an end to deposition and eventually led to the deformation of the whole series by elevation, folding, and faulting.

DEFORMATION AND EROSION.

The folding and faulting to which both the sedimentary and igneous rocks have been subjected were occasioned to some extent by the subsidence of the Piedmont region during the accumulation of the sediments, but much more by the uplift that reversed the direction of movement, raised the whole formation, and gently tilted it to the northwest. In some places the strata were wrinkled into low folds, and two great faults displaced the central portions in the southwestern part of the New Jersey area. Other faults are found to determine the greater portion of the northwestern boundary, and numerous smaller ones occur throughout the region. The boundary faults belong to the preceding period of depression, and possibly some of the others also date their beginnings from that period.

It is a point worthy of note that, almost without exception, the known faults of the Newark strata in New Jersey have the downward displacement on the southeast side and the up-throw on the northwest side of the fissure. Bearing in mind the further fact that the sandstones and shales of this series usually dip northwestward from 10 to 15 degrees in quite a regular monocline, it is readily understood how the great Hopewell and Flemington faults of the southwest (Pl. XXVIII), involving displacements of many thousands of feet, have caused a threefold repetition of the stata and their included trap sheets along the Delaware River above Trenton. Thus at least half of the great width of the Newark belt in that region is due to this repetition of the series by faulting.

No such great faults are known in the central and northeastern parts of the belt, but displacements of smaller amounts,

ranging from less than a foot to several hundred feet, are frequent in the trap sheets of the Palisades and the Watchung Mountains; and occasionally in fresh exposures of the rocks, similar faults are observed in the sediments. The monotonous uniformity of the shales and the sandstones, however, renders the detection of such faults well nigh impossible under ordinary conditions, apart from the trap sheets. Under the very probable assumption that the intervening areas are as greatly affected in proportion as the trap outrops, it will be seen that no inconsiderable fraction of the width in the central and northeastern portions of the Newark area is probably due to repetition on a small scale by numerous faults.

These movements of faulting and folding, together with the enormous erosion which the entire region has since undergone, have been the determining causes of the present topography, particularly the altitude and location of the trap ridges. The causes of these movements have been fully discussed by previous writers.[1]

The Supposed Fault Along the Hudson River.

It has been often supposed that the southeastern boundary of the Newark along the Hudson River has been determined by a fault, and that in a measure this fault has influenced the lower course of the river. The existence of such a fault has not been fully established, however, since very little is known of the nature of the contact between the Newark strata and the crystalline foundation on which they rest. Several deep wells in Hoboken, Jersey City, and Bayonne[2] that have penetrated from 1,000 to 2,000 feet of sandstone very near the border seem to lend support to the fault hypothesis; but in all cases these may also be explained as normal overlaps with the Newark strata dipping 15 to 20 degrees to the west.

[1]Davis, 7th Ann. Rep. U. S. Geol. Survey, pp. 484–487. See also 18th Ann. Rep. U. S. Geol. Survey, p. 140; Ann. Rep. State Geologist of N. J. for 1897, p. 146.

[2]Ann Rep. State Geologist of N. J. 1882, p. 140; 1898, p. 139; 1904, pp. 264, 266.

Neither is it necessary to suppose an intervening fault in order to explain the contraposition of the Palisades with their underlying shales and sandstones on one side of the river and the prominent hills of crystalline rocks on the other. The projection of the lowest strata across the Hudson with a dip much less than the average in this vicinity would carry them well over the tops of the opposite hills. In fact the characters of both the sediments and the trap of the Palisades make it quite certain that these rocks once extended considerably further northeastward than their present limits; and from the theory of continental origin of the sediments here advocated it is not at all improbable that they were formerly continuous with those of the Southbury and Connecticut Valley areas of Connecticut. Evidence of such an extension for the Palisades trap sheet has been recently presented by Julien.[1]

Age of the Faults.

That the principal period of faulting was subsequent to the formation of the intrusive trap masses, as well as the sediments and the extrusives is evident from the following considerations: (1) The numerous faults by which all these rocks are displaecd throughout the area. (Pl. XXVIII). (2) The shearing off of one side of the Passaic Basin syncline, including the extrusive trap sheets and the uppermost strata of the series, by one of the great faults of the northwestern boundary, and the arms of the intrusive trap of Cushetunk Mountain by another. (3) The extrusive trap at Sand Brook is cut and the great intrusives of Sourland Mountain, Mount Gilboa, and Byram are brought up in a repeated sedimentary series by the Hopewell and Flemington faults. (4) No intrusive trap in the Newark area has yet been found to follow or to send off branches along any of these fault fissures, and hence there is no evidence of igneous activity either during or subsequent to these disturbances.

April 10, 1907.

[1] Science, New Series, vol. 25, 1907, p. 184.

The Newark (Triassic) Copper Ores of New Jersey.

BY J. VOLNEY LEWIS.

CONTENTS.

INTRODUCTION.

Since early in the eighteenth century the copper deposits of New Jersey have attracted more or less attention, and have been the objects of repeated attempts to mine and smelt them. In the early days some of these efforts were quite successful for the times; but for half a century, at least, they have uniformly led to disappointment and failure, and since the development of the great native copper deposits of Lake Superior and the extensive ore deposits of the west and southwest they have almost dropped out of mind. From time to time, however, one locality or another has been taken up, some of the old workings reopened and perhaps a little additional work done, only to be abandoned again after a few months or a few years. Such, in brief, has been the history of the New Jersey copper industry for nearly two centuries. Since the establishment of the State Geological Survey the various reports have recorded the rise and fall of these periodical waves of interest.

The fact is that, with one or two exceptions, little or nothing is positively known of the degree of success attained in the early operations, except that for one reason or another they were not permanently successful. It is known, however, that it was often difficult, and even impossible, to drain the workings except to very shallow depths; that concentration, beyond hand cobbing, was in most cases crude and inefficient; and that, in the later times, efforts have often been ill-directed and money wasted for useless appliances.

It may reasonably be questioned whether, in any case, the average grade of available ore has been satisfactorily established, and it is quite certain that nowhere has the existence of any great body of ore yet been demonstrated. This is the more to be regretted because in some instances considerable deposits may reasonably be expected, and, with proper direction, the money already expended upon them would have determined the matter long ago. In the following report, however, all available information is given concerning every deposit of past or present importance, together with such conclusions as may safely be drawn from present knowledge, and, in a few cases, suggestions as to future operations.

Whether or not any of these mines shall ever again prove commercially profitable, they constitute an exceedingly interesting example of a class of ore-deposits, and are of considerable importance in investigating the principles of their origin. It is hoped that the discussion under this head may contribute something toward the advancement of this branch of applied geology. This will have been accomplished, in a measure at least, if these observations serve to direct the attention of geologists to these deposits and to stimulate discussion.

ACKNOWLEDGMENTS.

The author is especially indebted to Mr. W. S. Valiant, assistant in the Geological Museum of Rutgers College, for careful and thorough determination and verification of the minerals encountered in the ores and trap rocks in this study. Thanks are

also due to the officers and owners of the mines near Rocky Hill, Arlington, and Somerville for courtesies extended in the examination of the properties, and to Mr. Thomas A. Edison for information in regard to the old workings near Menlo Park. Reports and published articles referred to in the text are duly acknowledged in footnotes.

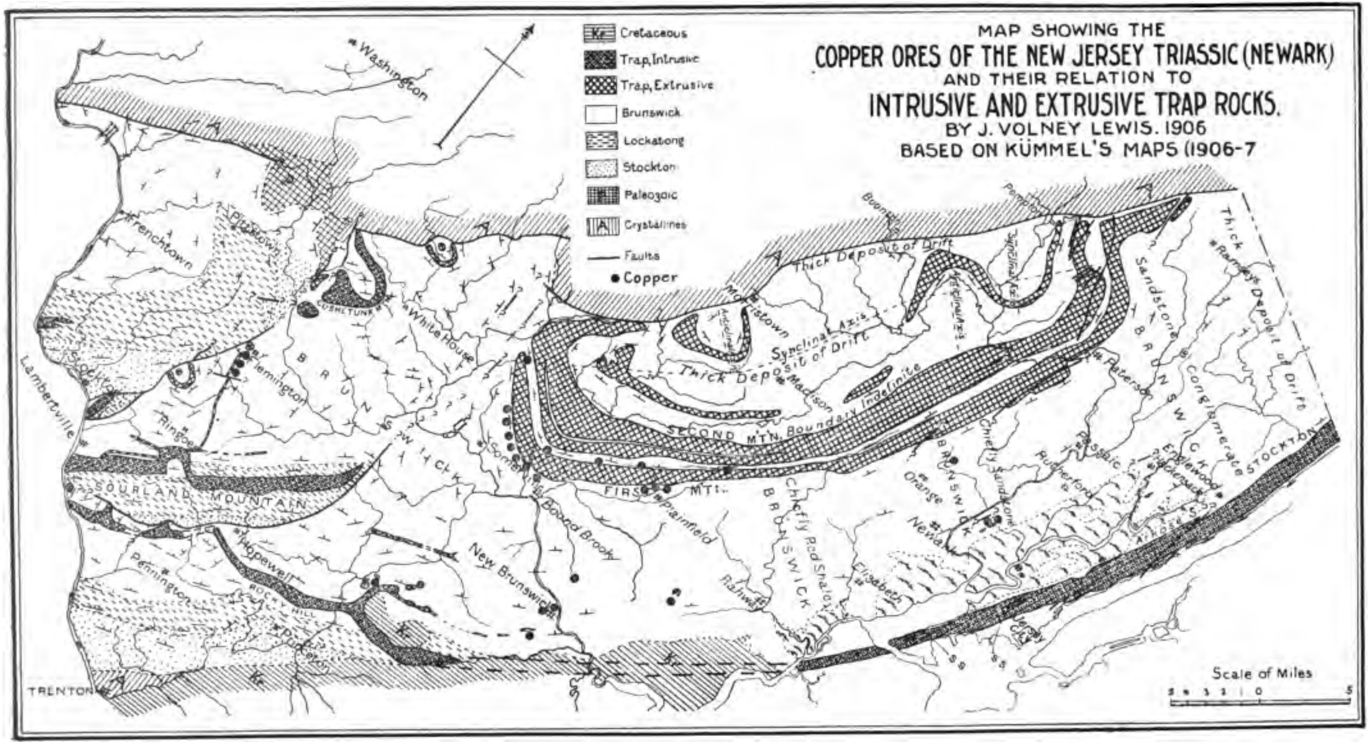
COPPER-BEARING MINERALS IN THE TRAP.

Visible grains of *chalcopyrite* (the brassy-yellow copper-iron sulphide) are not infrequently found in the trap rocks, particularly in the intrusives, where the constituent minerals are developed in larger grains and hence are more distinct. The same mineral also occurs commonly with the abundant calcite and zeolites resulting from the alteration of the more vesicular and cavernous portions of the extrusive traps, and in veins of similar secondary minerals generally. Flakes and thin sheets of metallic copper are also found in veins and joint-cracks, and more rarely rounded shot-like and irregular granules of copper occur in the more massive portions of the trap of First Mountain. Such occurrences are frequently encountered in the American Copper Company's mine north of Somerville and in the quarries at Chimney Rock, north of Bound Brook. At the latter locality metallic copper is sometimes found in the trap as much as 40 or 50 feet from the base of the sheet.

Copper is also known to occur as a constituent of the pyroxenes, the principal dark-colored mineral of the trap rocks. Weed[1] cites 200 assays of the trap of First Mountain, made for Josiah Bond, which yielded an average of one-fortieth of one per cent. of copper. The fresh central portions of trap prisms were also crushed and the heavy minerals concentrated by "horning." These, upon examination by Hillebrand, in the laboratory of the United States Geological Survey, showed an appreciable amount of copper.

For the purposes of this investigation, typical specimens of the coarse-grained intrusive trap from the quarry at Rocky Hill

[1]Ann. Rep. of State Geologist for 1902, p. 136.


MAP SHOWING THE
COPPER ORES OF THE NEW JERSEY TRIASSIC (NEWARK)
AND THEIR RELATION TO
INTRUSIVE AND EXTRUSIVE TRAP ROCKS.
BY J. VOLNEY LEWIS. 1906
BASED ON KÜMMEL'S MAPS (1906-7
Cretaceous
Trap, Intrusive
Trap, Extrusive
Brunswick
Lockatong
Stockton
Paleozoic
Crystallines
Faults
Copper
Washington
Frenchtown
Lambertville
Flemington
White House
Ringoes
SOURLAND MOUNTAIN
Hopewell
Pennington
ROCKY HILL
Princeton
TRENTON
New Brunswick
Bound Brook
Plainfield
FIRST MT'N.
SECOND MT'N. Boundary Indefinite
Thick Deposit of Drift
Synclinal Axis
Anticlinal Axis
Morristown
Madison
Boonton
Pompton
Paterson
Chiefly Red Shale
BRUNSWICK
Rahway
Elizabeth
Newark
Orange
Chiefly Sandstone
Rutherford
Passaic
Englewood
Hackensack
Sandstone & Conglomerate
Thick Ramsey Deposit of Drift
STOCKTON
Jersey City
Scale of Miles

were crushed, and separated by heavy solution in the laboratory of the Geological Survey. The pyroxene thus obtained was tested for copper by Mr. R. B. Gage, and yielded 0.019 per cent., nearly one-fiftieth of one per cent.

Along oxidized and stained joint-cracks of the various trap masses *chrysocolla* (the bluish-green copper silicate), a little *malachite* (the green carbonate) and, more rarely, *azurite* (the blue carbonate), not infrequently occur. These are manifestly the results of alteration of some of the copper-bearing constituents of the trap described above, by means of the percolating surface waters that have partially altered the trap itself.

COPPER ORES IN THE SEDIMENTARY ROCKS.

The only ores of copper that have thus far attracted attention in the Newark rocks of New Jersey as of possible commercial value occur in the shales and sandstones. (See Pl. XXX.) They consist of disseminated grains and irregular masses, with occasional vein-like aggregates and impregnated fault-breccias. Seventy years ago Professor Rogers concluded "that the ore does not exist in any instance in the shape of a true vein," but that it "has been injected into the body of the red shale and sandstone" of the regular stratified series.[1]

The principal copper-bearing minerals are *chalcocite* (copper glance, the black copper sulphide), and *native copper*. Associated with these are varying amounts of secondary copper minerals that have resulted from alteration by surface waters. The chief of these is *chrysocolla*[2] (the bluish-green copper sili-

[1] Report of the Geol. Survey of N. J., Henry D. Rogers, Philadelphia, 1836, pp. 167, 169.

[2] Without exception the available literature of the Newark copper deposits places the emphasis on malachite as the important secondary ore, whereas the present studies of the copper minerals, both in the mines and in the collections at Rutgers College, show a great preponderance of chrysocolla in every instance. More or less green carbonate is usually present (rarely azurite), but the silicate occurs in great abundance. This curious predilection for malachite is doubtless the result of unverified tradition accepted without question by each succeeding generation, since the error was not sufficiently evident to be detected on casual inspection.

cate), and there are smaller quantities of *cuprite* (the red copper oxide), *malachite* (the green copper carbonate) and *azurite* (the blue copper carbonate).

The modes of occurrence and associations of these ores are quite varied, as regards both the sedimentary and the igneous rocks. They may be classified, however, under four distinct types, two with and two without accompanying intrusive traps, as follows:

I. With intrusive trap rocks.

1. In the zone of metamorphic, or "baked," sedimentary rocks accompanying the intrusive traps, as at the Griggstown (Rocky Hill) mine.

2. In unaltered sandstones and shales intersected by small trap dikes, as in the Arlington and Flemington mines.

II. Without associated intrusives.

1. In unaltered (or but slightly altered) strata associated with extrusive trap sheets, as at numerous localities along First Mountain, near Pluckamin, Somerville, Bound Brook and Plainfield.

2. In unaltered strata entirely apart from known trap masses of any kind, as at New Brunswick, Glen Ridge and Newtown.

THE GRIGGSTOWN (ROCKY HILL) COPPER MINE.

Location.—This mine, the property of the New Jersey Copper Company, is located 1 mile south of Griggstown, 2 miles northeast of Rocky Hill, the nearest railway station, and ½ a mile east of the Millstone River and the Delaware and Raritan Canal. It has also been called the Franklin mine.

History.—As early as 1753 a newspaper reported that "a valuable Copper Vein of Six Foot Square is very lately found there,"[1] and various shares in the mine were offered for sale about 12 years later. It is said that 160 Welsh miners were employed in the mine at one time before the Revolutionary War, and that considerable ore was concentrated and shipped to England. It

[1] Pennsylvania Gazette, Jan. 16, 1753, reprinted in New Jersey Archives, vol. XIX, p. 234.

was again operated early in the nineteenth century and several later attempts have been made to work the mine by reopening portions of the old workings. In 1906 the deepest shaft was cleared to the bottom, probably for the first time in over a century.

Extent of workings.—The principal shaft is 190 feet deep (Fig. 5). The workings of the first level, about 100 feet deep,

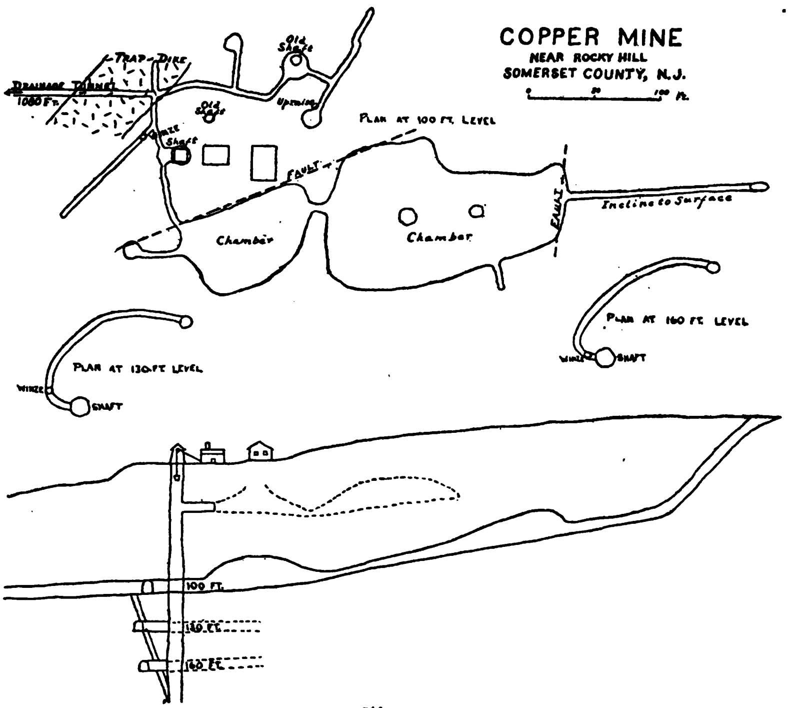


Fig. 5.

Map and section of the old workings at the Rocky Hill Mine (Griggstown).

also communicate with the surface by an inclined shaft and by a drainage tunnel 1080 feet long. There are several other shafts now caved in, and some stoped-out chambers of considerable size, as shown in figure 5.

Geology.—The crest of the ridge rising east of the mine is the outcrop of coarse-grained intrusive trap rock, which continues southwestward and connects with the larger sill of similar

rock that forms the crest of Tenmile Hill and Rocky Hill. This northeastward offshoot of the trap has been intruded conformably between the strata of the shales, which strike N. 45° E. at the mine and dip from 10° to 20° N.W. Throughout the length of this ridge and westward along Rocky Hill, the shales overlying the trap have been greatly altered by the heat of the intrusive mass. This is most noticeable in the change of color which they have undergone. On the lower slopes of the ridge, below the mine, the normal dark-red color appears. Further up the slopes this gradually changes, through various shades of purple to the dark-gray, brown and almost black hornstone that is found in the mine. It is often thickly spotted with rounded and rectangular masses of chlorite (probably an alteration product of cordierite), ranging in size from minute specks to an inch in diameter.

Offshoots of the underlying trap sill form several dikes through the shales. One of these about 60 feet thick was cut in the workings just west of the shaft, and several oval and irregular outcrops appear in the vicinity to the west and north of the mine. It is clear also that the trap cannot lie far below the present workings, if it continues approximately conformable to the strata, and any great extension in the depth of the mine would have to be made to the northwest.

Character of the ores.—The essential ore at this mine is *chalcocite,* or glance (the black copper sulphide), with occasionally a little *chalcopyrite* (the brassy-yellow copper sulphide), and small quantities of secondary *chrysocolla* (the bluish-green copper silicate), *malachite* (the green copper carbonate), and *cuprite* (the red copper oxide). Associated with the ore-minerals are frequently found tourmaline, magnetite, hematite, epidote, and occasional feldspar crystals, besides the abundant nodules of chlorite, described above.

Native copper, tenorite and bornite have been reported from this mine,[1] but a careful search of the mine, the old dumps, and old collections from this locality in the Geological Museum of Rutgers College failed to verify any of these. A small quantity of native copper is, however, to be expected, and the chalcocite

[1] Weed, Bull. U. S. Geol. Survey, No. 225, p. 188.

is frequently so intimately mingled with magnetite and hematite, as shown by microscopic sections of the ore, as to be readily mistaken for bornite with the ordinary blowpipe reactions. Some of the soft black masses of magnetite, hematite, or tourmaline also present physical characters much like tenorite.

Occurrence of the ores.—Chalcocite is the original ore. It occurs in fissures and brecciated zones in the hard, flinty hornstone, which is sometimes bleached to a light gray or white in the vicinity of the ore. The chalcocite also penetrates minute cracks in the hornstone, and occurs as a constituent of some of the chlorite nodules with which the stone is often thickly studded. One of the bedding-planes of the hornstone carries from 3 to 12 inches or more of soft, clay-like material charged with ore. This material bears evidence of slipping, and seems to have been developed along a thrustplane following the stratification. It seems to have furnished most of the ore in the earlier workings.

The secondary ores, chrysocolla, cuprite, and malachite, formed from the later alteration of chalcocite and chalcopyrite by percolating surface waters, occur with the primary ores in the fissures and brecciated zones. They also penetrate the adjoining strata along joints and bedding planes to a considerable distance, and large masses of the rock are sometimes impregnated with the green stains of chrysocolla. Cuprite and malachite are far less abundant.

Prospects.—So far as accessible the old workings do not show any considerable amount of workable ore. All such bodies as were encountered seem to have been pretty thoroughly stoped out. The conditions under which the ores were found seem to be of greater extent than the old workings, however, both laterally and in depth, so far as may be judged from those at present known. Since the mine has been reopened probably to the greatest depth attained here, it is worth while to determine whether or not this is true, and if so to extend the drifts beyond the limits of the old workings in prospecting for further bodies of workable ore.

THE ARLINGTON (SCHUYLER) COPPER MINE.

Location and history.—This mine is located in North Arlington, Hudson County, about a mile northeast of Arlington station

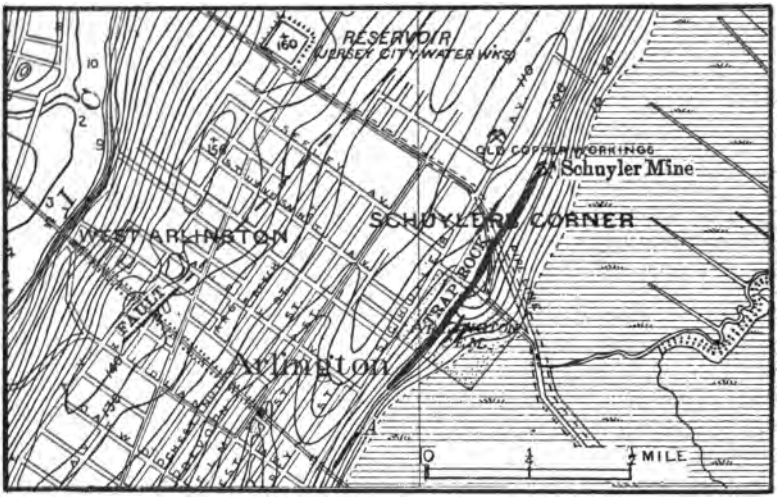


Fig. 6.
Map of Arlington, showing trap rocks, fault and old copper workings (Schuyler Mine), after Darton.

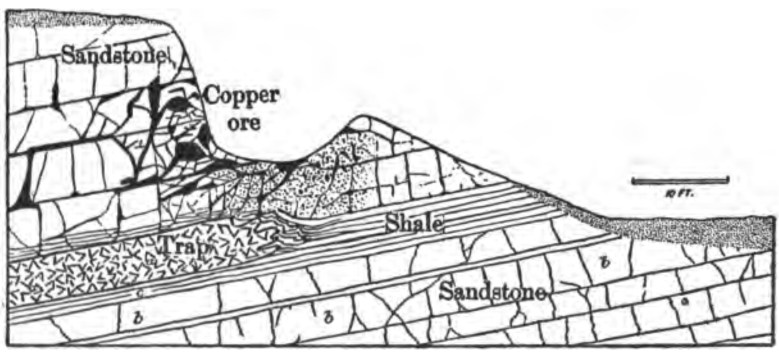


Fig. 7.
Cross section at A, figure 6, Arlington (after Darton).

on the N. Y. & Greenwood Lake Railroad, and about 8 miles from New York City. (Fig. 6.) It is the oldest mine in the State and was probably the first copper mine operated in America.

It was discovered early in the eighteenth century, probably about 1719, and a shipment of 110 casks of ore from New York in 1721 was probably the first exported from this mine. In spite of serious trouble with water in the lower levels, the mine was extensively worked in Colonial times and was a source of considerable wealth, for the times, to its owners, the Schuyler family. Since the Revolution the mine has been repeatedly reopened and operated for longer or shorter periods, and at one time (1859-1865) it is said that 200 laborers were employed in the mine and mills. An expensive mill and reduction plant designed to treat 125 tons a day were erected at the mine in 1900, but short experimental runs proved that it was not adapted to the ore, and the mine has now lain idle for several years.

Extent of workings.—"The Victoria shaft is reported to be 347 feet deep, but all is mud below the 240-foot level and difficult of access. (Fig. 8.) The old Cornish pump is still in position in the bottom of the shaft, buried in mud and fallen timbers. It is said that there are three drifts from the bottom of the shaft, one toward the northwest about 180 feet long, one running southwest 180 feet long, and the third running north about 210 feet. The mill at this time was near the mine and had 25 stamps of the old Cornish type with wooden stems. The ore as it came from the mine was cobbed and handpicked. The high-grade material was shipped without further treatment, and the lower grade was concentrated by jigs and buddles." [1] In all 42 shafts are said to have been sunk on the property, but only one, the Victoria, has been kept open. There are also 3 drain tunnels, one of which drains the mine to the 100-foot level. Two inclines have been run in from the face of the bluff overlooking the Newark Meadows. One of these is 220 feet long and the other 80 feet.[2] Figure 8 shows the workings above the 240-foot level.

Nature and occurrence of ores.—The ore at Arlington is *chalcocite,* or copper glance (the black copper sulphide) with much

[1] J. H. Granberry, Engineering & Mining Jour., vol. LXXXII, 1906, p. 1118.

[2] Annual Report of State Geologist for 1902, p. 129. The number of shafts has also been given as 32, and other details of the old workings vary somewhat in the different descriptions. See Engineering & Mining Journal, Vol. 69, 1900, p. 135, and Vol. 82, 1906, p. 1116.

secondary *chrysocolla* (the bluish-green copper silicate), and smaller amounts of *malachite* (the green copper carbonate). A little *azurite* (the blue copper carbonate), *cuprite* (the red copper oxide), and occasional particles of *native copper* are also found. The ore occurs in unaltered gray arkosic sandstone, which is

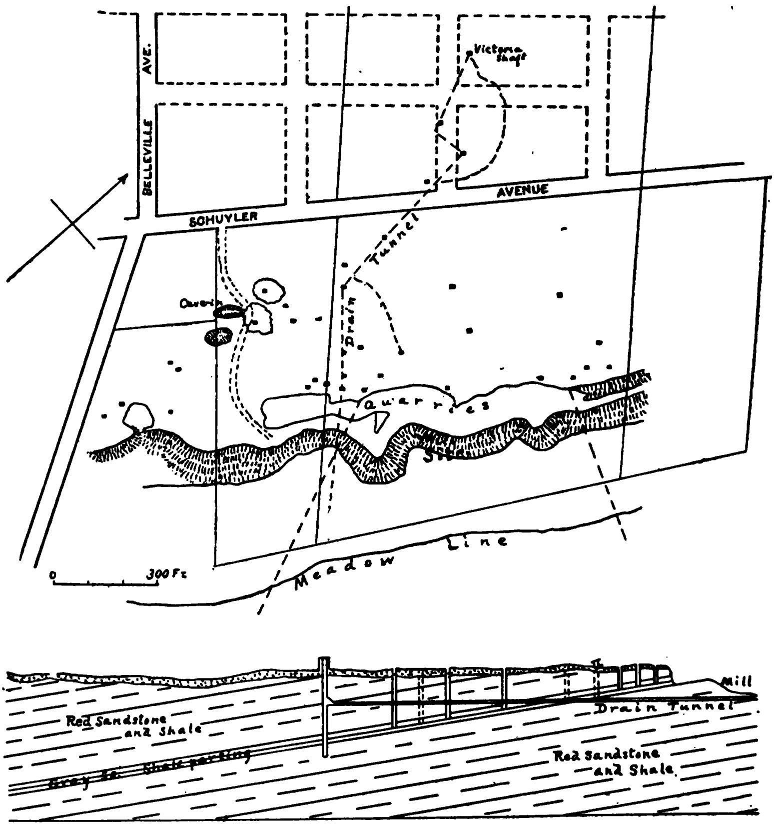


Fig. 8.

Map and section of the old workings at the Schuyler Copper Mine. (After Engineering and Mining Journal, vol. 69, p. 135.)

penetrated by small irregular branching trap dikes and overlain by red shale. The chalcocite is found chiefly in branching veins and seams in the sandstone near the small dikes and in the frequent fault breccias of sandstone and trap. (Compare fig. 7.) The larger pockets of the ore sometimes exhibit cleavage faces

an inch in width. These masses are sometimes thickly filled with quartz grains or with minute reddish crystals of feldspar. The sandstone is irregularly stained with the green chrysocolla and also contains occasional scattering grains of chalcocite. This impregnated sandstone occurs in two layers, the upper about 12 feet thick and the lower about 10 feet, separated by one foot of shale. these have a westerly dip of about 9 degrees. The workings have been chiefly confined to the upper sandstone.

"Over wide areas in this mine the surface of this sheet [of intrusive trap] is smooth and conformable to the gently dipping sandstones, but there are irregularities in which the strata are crossed for a few feet, and the sheet also sends several offshoots up into the sandstone. It is stated that the diabase surface was followed westward for a half a mile in the mining operations, and that at one point it is traversed by a fault of considerable amount." [1]

Prospects.—Systematic sampling by a competent mining engineer in 1900 is said to have given an average of slightly more than 2 per cent. of copper for the upper sandstone, as exposed in the present workings, and a little less than that amount for the lower sandstone. A small amount of silver is always present, but probably not enough to repay cost of recovery.[2] If an average of 2 per cent. copper content can be established over any large part of the property, the question of successful mining would seem to resolve itself into the questions of economic reduction and competent management. The sandstone can be mined and crushed very cheaply on a large scale, and rich seams and pockets of glance in the fault breccias and along the courses of the thin trap dikes might be expected to add appreciably to the output of the mine in the future, as they have done in the past. At any rate the mine is worthy of conservative investigation, in spite of past failures, by extending the drifts so as to block out systematically a large

[1] N. H. Darton, U. S. Geol. Survey, Folio No. 83, p. 10.

[2] It is of interest in this connection to note that a blowpipe assay of a rich specimen of ore from this mine, made in the Mineralogical Laboratory of Rutgers College by Mr. Harry R. Lee, yielded 4.4 oz. of silver per ton and a gold bead that was distinctly visible.

body of ore, or by thorough exploration with a core-drill. If a large body of workable ore can be thus established, the most economical method of treatment should be very carefully determined and the plant so modified as to adapt it to the character of the ore.

THE FLEMINGTON COPPER MINE.

Location and history.—The mine is located half a mile southwest of the court house in the town of Flemington, Hunterdon County. The ore was evidently discovered prior to 1834, since it is referred to in a publication of that date as having been "lately discovered, but not yet extensively explored."[1] It has been said that work was also done here "in the early days," but there seems to be no record of this. Active operations were under way, however, at the time of Professor Rogers visit in 1835,[2] and it is said that $400,000 were expended in opening and equipping the mine. Afterwards various attempts to operate it were made by several companies, and much prospecting was done in the effort to establish mines in the region from Flemington to Copper Hill, 2 miles to the south. All of these undertakings were soon abandoned, however, and no active operations have been attempted since 1860.[3]

Extent of workings.—The workings were located immediately beside a brook, and pumping must have been necessary from the beginning. A mill and a smelter were erected, of perhaps 25 tons capacity, judging from the dilapidated portions of the plant still standing, and considerable active work was done, as attested by the large dump-heaps about the old shafts. Several shafts were opened, but their depth and the extent of other underground workings have not been learned.

Character and occurrence of ores.—The ore was found in partly altered brownish-red and purplish shales in the vicinity of trap dikes. It consisted essentially of *chalcocite* (the black copper sul-

[1] A Gazetteer of the State of New Jersey, by Thos. F. Gordon, Trenton, 1834.
[2] Rept. Geol. Sur. of N. J., by Henry D. Rogers, Philadelphia, 1836, p. 167.
[3] History of Hunterdon and Somerset Counties, New Jersey, by Jas. P. Snell, Philadelphia, 1881.

phide), *cuprite* (the red copper oxide), *chrysocolla* (the bluish-green copper silicate), and *malachite* (the green copper carbonate), associated with calcite. *Chalcopyrite* (the brass-yellow iron-copper sulphide) is often disseminated in grains through the larger masses of chalcocite. A series of trap dikes cuts the shales and sandstones northward from the great intrusive sill of Sourland Mountain to Flemington. It is in the sediments accompanying these dikes that the copper ores of the region from Copper Hill to Flemington occur.

Professor Rogers[1] described the conditions in a series of east and west cuttings that were being made across the ore-body at the time of his visit. "A belt of metalliferous rock" was uncovered "of very variable width, sometimes as wide as 20 or 30 feet, which preserves nearly a north and south direction for several hundred feet," with strong indications of a precisely similar ore 2 miles to the south. The ore is described as "intimately blended or incorporated with the semi-indurated and altered sandstone, and the mass has therefore somewhat the aspect in certain portions of a conglomerate of recemented fragments, the metalliferous part being the cement. Most commonly the ore is thus minutely disseminated, though now and then it occurs in lumps of great purity and considerable size."

Prospects.—The geological conditions are seen to be closely similar in many respects to those of the Schuyler mine at Arlington, but much less is known of the value and extent of the ore bodies encountered. In the absence of such information, nothing can be said that might in any way offset the discouraging experience of those who have attempted at various times to operate the mine.

THE SOMERVILLE COPPER MINE.

Location and history.—This is the old Bridgewater mine, located 3 miles north of Somerville, Somerset County, on the

[1] Rept. Geol. Sur. of N. J., by H. D. Rogers, Philadelphia, 1836, p. 169.

southwestern slopes of First Mountain. The ore was known here and some of the old drifts in the vicinity were run before the Revolutionary war. Active work was again begun in 1821 and continued more or less intermittently at many points from this mine southeastward to Chimney Rock, a distance of 4 miles, during the next two decades. In the meantime a smelter was erected at Chimney Rock and another near the Bridgewater mine. Some mining was also done east of Chimney Rock in 1866. No further work was done until 1881, when explorations were again begun at the Somerville mine, and drifts were run into the mountain side along the contact of the trap and the underlying shales. Similar exploratory work has been done at intervals since, especially in the extension of the work along the under contact of the trap.

Extent of workings.—The principal opening is a sloping tunnel, or incline, following the contact of the shales with the overlying trap, as explained above. This contact plane dips slightly more than 10 degrees toward the northeast, and the tunnel has been driven into the mountain 1,240 feet. Drifts of varying length have been opened on alternate sides of the incline at intervals of 30 feet, and in a few instances considerable chambers have been excavated. The aggregate length of incline is 1,400 feet, and of side drifts 2,040 feet. A drainage tunnel catches the surface waters that find their way into the mine and also drains the upper workings. The water from the lower portions is also pumped into this tunnel.

The old dumps along the mountain slopes toward the southeast show that many tunnels of considerable length have been run between the mine and Chimney Rock. On the east side of the gorge at Chimney Rock, also, a tunnel 300 feet long runs into the mountain to the contact of the trap and branches each way along this contact for 100 feet, while another tunnel was driven only 20 feet below it.[1]

Equipment.—The mining plant consists of an 80-horse power boiler, a 5-drill Rand compressor, running drills and pumps, and a hoist with a 12-horse power Lidgerwood engine. The 50-ton

[1] Cook, Geology of New Jersey, 1868, p. 677.

mill is equipped with 60-horse power boiler and engine, crusher, two sets of roughing rolls, drying screens, sizer, and two Wilfley tables.[1]

Character of the ore.—The ore of the Somerville mine is essentially *native copper,* altered above the depth of 100 feet (600 feet on the slope) to *cuprite* (red copper oxide), *chrysocolla* (green copper silicate), and *malachite* (the green copper carbonate). Small grains and crystals of *chalcocite* (black copper sulphide) and occasional particles of *chalcopyrite* (the brass-yellow iron-copper sulphide) also occur, besides small amounts of *hydrocuprite* (orange-colored hydrous copper oxide). The copper is silver-bearing and now and then small masses of native silver are found.

Occurrence of the ore.—The ore occurs chiefly in the upper two and a half feet of shales (varying from 1 to 3 feet) immediately underlying the extrusive trap sheet, and penetrating the trap itself usually to a distance of about 6 inches from the contact with the shales. Locally the copper is found to extend to much greater distances in both the shales and the trap. In driving the drainage tunnel in the underlying shales, metallic copper was found in nodules 8 feet below the trap, and a sheet of cuprite coated with malachite was encountered 15 feet below the contact.[2] In the trap quarries at Chimney Rock, on the other hand, numerous nodules flakes and sheets of copper have been found in the trap as much as 40 or 50 feet above the base of the sheet.

In the shales the copper occurs in minute grains and strings and in nodules, sheets, and ragged masses of great variety of form and size. Many years ago a mass plowed up in a field on the mountain slope near the mine is said to have weighed 128 pounds. A portion of it now in the Geological Museum of Rutgers College weighs 74 pounds, including perhaps a pound of attached and included shale. The shale containing the copper is bleached to various shades of reddish brown, gray and almost white. Immediately about even the smallest grains, and to a

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[1] Ann. Rep. State Geologist for 1902, p. 129.

[2] Ann Report of State Geologist of N. J. for 1903, p. 109.

varying distance (a fraction of an inch to one or two inches) from them, the inclosing shale is invariably of much lighter color than the prevailing brownish red of other portions of the same stratum and of adjacent regions. These bleached spots and mottlings, while fairly well defined, are not separated by a sharp boundary from the surrounding red shale. There is generally a distinct transition zone of intermediate shades from an eighth to a quarter of an inch or more in width. Also the thin lamination, which is distinct in normal portions of the rock, often disappears altogether in the bleached spots about the copper.

The red shales of this and adjoining regions to the south, east and west are frequently interspersed with thin tabular crystals and clusters of calcite, which range in size from almost invisible to more than an inch in diameter. (Pl. XXXI, A.) They are apparently low flat rhombohedra. Often near the surface and usually in the mine this calcite has been partly or wholly removed by solution. In adjacent regions the cavities are often lined with microscopic quartz crystals, and sometimes divided by thin partitions of quartz, presumably deposited along cleavage planes of the calcite. In the mine, where the cavities are all quite small, slit-like openings, they are often partly occupied by little masses of copper and crystals of chalcocite; and this is equally true of both the bleached and unbleached portions of the shale. (Pl. XXXI, B.) It would seem, therefore, that these belong to a different period of formation from that of the principal mass of the ore, which was deposited only in the bleached areas of the shale. Occasional crystals of prehnite and chalcopyrite also occur in these minute cavities near the trap.

In the upper 600 feet of the slope most of the copper has been oxidized to cuprite, chrysocolla and malachite, which replace the disseminated particles, sheets and masses of the metal. The base of the trap sheet is often vesicular and the cavities have been filled with quartz, manganocalcite and zeolites, with frequent lumps and stringers of copper. A northeast-southwest fault encountered in the workings has displaced the strata about 4 feet, and has crushed and sheared the rocks considerably in places.

Prospects.—The mine requires no timbering, the overlying sheet of solid trap forming a perfect roof. The ore is easily

Fig. A. Red shale with desseminated lenticular calcite. New Brunswick.

Fig. B. Shale with slit-like cavities partially filled with copper and chalcocite. Somerville mine.

mined and crushed, the inclosing rock being softer than the somewhat similar ores of the Lake Superior region. There is no reason to doubt that the character of the ore will continue native copper in depth, as in the last 600 feet of the slope, which has evidently passed below the zone of oxidation. Repeated samplings in recent years are said to have yielded an average copper content of over 2 per cent. in the present workings. If a great body of ore of this grade can be fully established there seems to be no good reason why it should not be mined at a profit, if operated on a large scale. With the great advantages of its location as to labor and fuel supply and its accessibility to the markets of the East, its possibilities as a low-grade copper mine are worthy of investigation, and explorations should be sufficiently extended to determine definitely the question of available ore-supply for a considerable working period. Incidentally the character as well as the quality and quantity of the ore would thus be tested, and the type of mill required for its economical treatment could be fully determined experimentally. No extensive plant should be erected until this is done.

OLD MINES AT CHIMNEY ROCK AND PLAINFIELD.

Mines near Chimney Rock.—Similar conditions to those described, which prevail along First Mountain for 4 miles southeastward, led to considerable work in the early days as far as Chimney Rock and beyond. On both sides of the gorge of Middle Brook at Chimney Rock numerous old workings are found, and many of the drifts were several hundred feet in extent. One on the east side of the brook is said to have been driven in 300 feet to the trap and 100 feet each way along the contact. On the west side one of the old tunnels is said to have penetrated 700 feet. One of the old smelters, built early in the last century, was also located here. A drift now open beneath the trap quarry at Chimney Rock shows conditions almost identical with those described above, although the shales are somewhat less bleached about the disseminated ores than at the Somerville mine. Occasional pieces of native silver are also found associated with the

copper at this locality. As noted above, grains and strings of copper are now found here in the trap quarries as much as 40 or 50 feet above the base of the sheet.

Mines near Plainfield.—Northwest of Plainfield, in the gorge of Stony Brook through First Mountain, extensive explorations were made for copper early in the last century, and active mining was going on there at the time of Dr. Cook's visit in 1866, the ores being sent to Bergen Point. Work was being done by two companies at that time, and tunnels and drifts of several hundred feet had been opened on both sides of the gorge, the longest tunnel in each case being given as 400 feet.

The workings being in the oxidized zone the ores were the same as in the upper workings at the Somerville mine, impregnating the shale for a thickness of from 8 inches to 2½ feet from the trap. The shales here dip 10 to 20 degrees a little west of north. No ore was found in the base of the trap itself. Small faults of 3 or 4 feet throw were encountered in places.[1]

Prospects.—Practically nothing definite is known of the grade or extent of ore encountered in these old workings. As small undertakings, under the adverse conditions of earlier times, they were not successful, presumably for the reason that the amount of rich ore encountered was very small. If, however, future explorations should establish the existence of large bodies of workable low-grade ore at one point along the base of First Mountain, there would be every reason for the careful investigation of other points where similar deposits are known to exist.

COPPER DEPOSITS BACK OF FIRST MOUNTAIN.

The Hoffman mine.—Two miles northwest of the Somerville mine and three-fourths of a mile southeast of Pluckamin is the old Hoffman mine, which has been worked at various times and was said to have produced some ore for shipment. The shaft, 136 feet deep, penetrates the shales and sandstones and the underlying trap. The ore is said to be 4 feet thick and to carry

[1] Cook, Geology of New Jersey, 1868, pp. 676, 677.

some native copper. Materials collected from the old dump show chalcocite in sandstone and in brecciated trap, with smaller quantities of green carbonate (malachite). The breccia seems to indicate that the ore occurs in connection with a zone of faulting.

Pluckamin to Feltville.—From this point around the inner or back slope of First Mountain for a distance of 17 miles, copper minerals have been found at several places between the vesicular upper portions of the trap and the overlying sandstones and shales. Discovery of these minerals has led to prospecting in the vicinity of Martinsville, Warrenville, Washingtonville, and Feltville. The work at all these places was done many years ago, however, and the conditions encountered are not known. At Feltville the ore was said to be sulphide, probably the black sulphide, or glance, as at the Hoffman mine. It was associated with pyrite in a thin rock-seam between the trap and the shales. The contact as now exposed along the narrow ravine and in some of the old pits and drifts shows no copper minerals.

THE NEW BRUNSWICK COPPER MINES.

The New Brunswick or French mine.—About 1748 to 1750 many lumps of native copper weighing from 5 to 30 pounds each, "upwards of 200 pounds" in all, were plowed up in the field of Philip French, now Neilson Campus of Rutgers College, at New Brunswick. A company was formed to mine for copper in 1750 and work was begun by sinking a shaft the following year. Grains of the metal were found in the red shales and sheets in the joint-planes of the rock. Some of the latter of the "thickness of two pennies and three feet square" are said to have been found within 4 feet of the surface.

A depth of 60 feet or more was attained and some of the workings are said to have extended several hundred feet under the Raritan River, although there was much difficulty in handling the water. A stamp-mill was erected and many tons are said to have been shipped to England.[1] Similar sheets of metallic copper

[1] Morse's Gazetteer; Morse's "American Universal History," 1805; Barber and Howe's "Historical Collections of the State of N. J., New York, 1844."

from one-sixteenth to one-eighth of an inch in thickness and one or two feet across have been found in grading the street east of the campus of Rutgers College, and also in digging a cellar on Somerset street on the southwest side of the campus. The latter place has been recently partly exposed again, and the copper is found in a zone of bleached grayish shale and in spots of gray mottled with the normal red color along an east-west fissure. The conditions are an exact duplicate of those found at Menlo Park, described below, except in the direction of the fissure, which is at right angles. *Cuprite* (the red oxide) and *malachite* (the green carbonate), with occasionally a little *chrysocolla* (the silicate) and *azurite* (the blue carbonate), are sometimes found incrusting such metallic sheets or entirely replacing them in the joint cracks of the shales. There is no evidence or indication that trap rock was ever encountered in these old workings at New Brunswick. The well back of the Rutgers College gymnasium, 244 feet deep, and one at Johnson & Johnson's factory, 480 feet deep, are both in the immediate vicinity of the old copper mine, while the one on Bishop Place, 455 feet deep, is little more than a block to the north of it. In all of these the usual red shales of the region were penetrated, with occasional purplish and sandy layers. The purple shales, which are also occasionally seen at the surface in this vicinity, may indicate the presence of intrusive trap at no great depth.

The Raritan mine.—About 3 miles southwest of New Brunswick is the old Raritan mine. "The main shaft was 160 feet deep, from which a tunnel was driven in a north-northeast direction. Another shaft northeast of this one did not reach the ore. All of them are now filled with water. The rock of these shafts lying at the mouth of the mine is mostly red and bluish shales. Very little trap was seen in these rubbish heaps. The ore is mostly a carbonate with some sulphide. The difficulty in working this mine was the trouble with water."[1] The workings were not far from some small dikes that are known to intrude the shales in that vicinity, and may possibly have encountered some of these. Otherwise the conditions are apparently the same as at New Brunswick.

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[1] Cook, Geology of New Jersey, 1868, p. 679.

THE MENLO PARK COPPER MINE.

Location and history.—The old workings are half a mile north of Menlo Park and 7 miles northeast of New Brunswick. Copper was discovered here, it is said, about 1784,[1] and the workings were so old in 1820 that "no vestiges of copper remain upon the surface."[2] Attempts were made to work the mine before the war of 1812, again in 1827, and in the eighties of the last century. Later spasmodic efforts have been made from time to time, and a stock company, organized early in the present century, installed hoisting and pumping machinery, a tube mill, and jigs, and carried on explorations during the greater part of the year 1903. Nothing is known of the equipment used in the earlier work. So far as known, no ore was ever shipped, and the workings never proceeded beyond the stage of exploration. The deepest shaft is said to be 120 feet deep, with drifts and galleries of unknown extent.

Geologic conditions.—The shales of the vicinity have the usual bright-red to brownish-red color and dip 12 degrees toward the north. At the mine they are traversed by a vertical north-south fissure (Pl. XXXII), along which the movement has been parallel to the bedding, a nearly horizontal shove, or heave. This is indicated by both the slickensided walls and breccia of the fault and the abrupt termination of the fissure beneath undisturbed conformable shales above. The fault-breccia, varying from 6 inches to 2 feet in thickness, and about 3 feet of each wall of the fissure are composed of the dark-gray, nearly black, soft shale referred to as carrying the ore. On each side of the fissure this color quickly changes, after a little mottling of gray and red, into the normal red color of the typical Brunswick shales. In the different layers there is considerable irregularity in the distance at which this change takes place, but the average is perhaps 3 feet from the walls of the fissure. The zone of blackened

[1] W. W. Clayton, History of Union and Middlesex Counties, New Jersey, Philadelphia, 1882, p. 849.

[2] American Journal of Science, 1st ser., vol. 2, 1820, p. 198.

material traceable from the top of the fissure in a nearly horizontal position to the westward probably indicates that the heave here follows a bedding-plane. Owing to the indistinctness of the exposure, however, it is impossible to determine this point definitely. Locally the dark-gray shale is spotted and mottled to a slight extent by white bleached areas. No trap debris is visible about any of the workings, and probably none occurs here.

Character and occurrence of the ores.—The ore is *native copper,* altered in part to *chrysocolla* (green copper silicate), in dark-gray shale constituting the breccia and walls of a fault fissure. There are also minute grains of *chalcopyrite* (brass-yellow copper-iron sulphide) and of magnetite in the dark-colored shale.

The copper occurs as thin sheets and films in joint cracks of the dark-gray shale and plating the slickensided surfaces of the breccia and walls. In the form of minute grains and strings it also permeates the mass of the shale and occasional bituminous plant remains. Chrysocolla is chiefly confined to the joints and fissures, while chalcopyrite occurs very sparingly in minute disseminated particles through the body of the shale.

Prospects.—Mr. Thomas A. Edison, who did some work here about twenty-five years ago, writes in answer to an inquiry: "The ores were too lean to pay. Of the streak we worked, which was about four feet wide, the average was about one-half per cent." It is said that the last operations produced ore that averaged over 2 per cent., but authentic information to this effect is lacking. At any rate there seems little probability that there is a great body of ore at this place, such as a deposit of low grade would require for profitable exploitation, and there is, therefore, no encouragement for further expenditures in exploration.

COPPER ORES IN OTHER LOCALITIES.

Copper ores at Glen Ridge.—Traces of old workings are still to be seen at Glen Ridge, 4 miles northwest of Newark, in the area just east of the public school building. *Chalcocite* (black copper sulphide) and *chrysocolla* (the bluish-green silicate) are found penetrating and largely replacing bituminous plant remains

Heave fault. Old copper mine, near Menlo Park.

in black glossy masses looking much like anthracite coal. Gray sandstone is also stained green by impregnations of chrysocolla, as in the Arlington mine. No trap is known to occur here or in the surrounding region for several miles, and local outcrops are not sufficient to determine whether or not there are fault fissures in the strata. Copper minerals in exactly the same association are found in certain strata of the old sandstone quarries at Avondale, north of Newark and Belleville, and also in a quarry a mile and a half northeast of the Schuyler mine.

Copper and silver at Newtown.—Native silver in small scales and specks occurs in gray sandstone stained with chrysocolla on George Drake's farm at Newtown, 4 miles north of New Brunswick. Only surface specimens have been collected, and there has been no prospecting for ores. As at Glen Ridge, described above, no trap rocks occur here nor within a distance of several miles in the adjacent regions.

Copper ores at Fort Lee.—Small amounts of *chalcopyrite* (copper pyrites), with some *"malachite"* (probably *chrysocolla,* the silicate) were discovered in the sandstones under the trap of the Palisades at Fort Lee in very early times, and some exploratory work was done in the hope of developing a gold mine.

On Pennington Mountain.—On the southern and southwestern slopes of Pennington Mountain, 1 to 2 miles northwest of Pennington, traces of copper minerals have been found in the altered shales adjacent to the intrusive trap mass which forms the backbone of the mountain. These have led to occasional prospecting operations on a small scale, but no notable amount of ore has been located, nor is any to be expected.

Enough copper is often present to produce green chrysocolla stains in the shales and sandstones near the trap masses, both extrusive and intrusive, but experience teaches that it is not wise to base sanguine expectations of ore deposits on such "indications." Nothing illustrates better than such copper stains the accuracy of the old precept that "one swallow doesn't make a summer." At the various localities just described, Glen Ridge, Newtown, Fort Lee, and Pennington Mountain, known conditions give no reason to expect more than such scant discolorations.

ORIGIN OF THE NEWARK (TRIASSIC) COPPER ORES.

Whatever the economic aspects of these Triassic copper ores they must continue to possess considerable scientific interest as problems in ore-deposition. The comparatively simple structural relationships of the ores and associated rocks relieves them of the difficulties and uncertainties attendant upon the complicated structures that prevail in many important mining districts. The conclusions arrived at, when satisfactorily established, should therefore be correspondingly simpler and clearer and should find profitable application in regions where the problems are more involved. It is largely with a view to the scientific value of the deposits that these studies have been undertaken, and it is hoped that the attention of geologists may be drawn to both the importance and accessibility of these examples for the elucidation of questions of ore genesis.

Kemp[1] has suggested that the copper of these deposits has probably come from the chalcopyrite disseminated through the trap or from copper in the pyroxene of these rocks, but makes no reference to mode of accumulation.

Weed's hypothesis.—In 1902, Weed[2] suggested the possibility of some close connection between igneous activities and the origin of the ores associated with intrusive trap rocks. He says: "At Rocky Hill glance and hematite occur under conditions that suggest a hydrothermal origin, and at Arlington also the conditions indicate a reimpregnation of the overlying rocks, with subsequent slight alterations and migrations of the copper."

Later, however, after an examination of the Rocky Hill mine, he ascribes the ores to the influence of percolating surface waters in the partial alteration of the trap. He says:[3]

"The scientific interest of this deposit is very great on account of the evident reducing action of the hornblende and chlorite upon copper-bearing solutions, but the discussion of the origin

[1] Ore Deposits of the United States, 2d ed., p. 168; 5th ed., p. 223.

[2] Ann. Report State Geologist N. J. for 1902, p. 131.

[3] Bulletin U. S. Geological Survey No. 225, 1904, p. 189.

of the ore involves a consideration of the various cycles of uplift and erosion to which the region has been subjected since Triassic time, and the accompanying movements of percolating waters, which are supposed to have derived the copper from the alteration of the trap from a fresh basaltic lava or diabase sheet to its present somewhat altered condition."

This is the conclusion he had formerly arrived at in regard to the ores beneath the trap sheet of First Mountain, an extrusive mass.[1] For the latter he gives the following probable sequence of events: (*a*) Basalt chloritized, iron reduced from silicate to ferrous oxide; (*b*) calcite amygdules formed in basalt and pores of the altered shale bed; (*c*) copper dissolved out by percolating waters and carried downward; (*d*) copper and calcite deposited in pores of the ore; (*e*) glance reduced and ferric oxide reduced in white patches. For this last step he finds that "the readiest agent at hand to reduce the glance to native copper is humic acid in waters containing oxygen," and "where organic matter such as plant remains occurred, the copper sulphide would be reduced to native copper." He further supposes that the solutions carrying the copper "contained alkaline carbonates, and precipitated copper and glance with calcite."

Objections to Weed's hypothesis.—Many of the difficulties involved in the foregoing hypothesis were fully appreciated by the author himself, who, after summing up the conditions of occurrence, states that "it is hard to see how any single chemical sequence can account for facts apparently so contradictory, and it may be like Vogt's Norwegian cases, an example of reversed conditions." He also demonstrates how impossible it is to adapt the commonly accepted explanation of the Lake Superior ores to the New Jersey deposits. He says:

"From the complete absence of iron oxide with the copper ore, and from the fact that the native copper occurs *only* in those portions of the ore-bed in which the ferric oxide has been reduced, a phenomenon common to Bolivian and European deposits as well as these, it is evident that the commonly accepted explanation is not only not adequate, but contrary to the observed

[1] Annual Report of the State Geologist of N. J. for 1892, pp. 136-139.

facts. If it were the protoxide of iron or of magnetite ferrous solutions that caused the reductions we should have red spots and *ferric* oxide, one of the most insoluble and stable of substances, associated with the native copper."

Some further difficulties in the application of Weed's hypothesis may be enumerated as follows:

(1) The trap rock of First Mountain is not sufficiently altered to account for the ores underlying it. On the basis of one-fortieth of one per cent. of copper in the unaltered trap, one-fourth of this would have to be transferred without loss from a trap sheet 600 feet thick, in order to supply two feet of the underlying shales with an average of 2¼ per cent. of copper. The great bulk of the trap is believed to be much less altered than this supposition would demand.

(2) An intricate system of meteoric circulation would be required to account for the ores overlying the trap sheet on the back of First Mountain and for the deposits above the intrusive trap rocks at the Arlington and Rocky Hill mines. If these ores have been derived from the alteration of the underlying trap masses, as supposed by Weed, to supply those lying above the First Mountain trap an upward movement of the copper-bearing solutions is required, whereas exactly the reverse supposition has been made in order to bring down the copper for the ores beneath the trap.

(3) The ore at Arlington not only lies chiefly above the intrusive trap, but its amount is out of all proportion to the thin sheets of this rock that have thus far been found in the vicinity of the mine. No tests have been made to determine the copper content of the unaltered portions of these traps, but unless this should prove to be far in excess of examples thus far determined in the New Jersey traps, the ore bodies here would not only require all the copper from the accompanying dikes and sheets, but in addition a much larger supply would be needed from some unknown source.

(4) Weed supposes that the solutions carrying the copper "contained alkaline carbonates, and precipitated copper and glance with calcite" in a porous stratum of shale. An examination of the shales of the adjacent regions to the south and south-

west shows that the normal red Brunswick shales are often thickly interspersed with thin tabular crystals and clusters of crystals of calcite, which range in size from almost invisible to more than an inch in diameter. This calcite, therefore, is a normal constituent of the shales and has not been supplied from the trap, and the peculiar slit-like pores in the shale of the upper oxidized ores in the Somerville mine, are the result of leaching out of these tabular calcites.

(5) Calcite occurring in amygdaloids and in fissures of the trap and the shales has undoubtedly been derived, like the zeolites, from the alteration of the trap rocks by percolating waters, and is in no way to be associated in origin with the calcite in the body of the shales. Such calcite with accompanying zeolites doubtless began to form with the beginning of erosion and percolating waters inaugurated by the deformation of the Newark strata, and continues to the present time.

(6) While the humic acid supposed to reduce the copper to a native metallic state is presumably furnished by percolating waters from the surface, it is also supposed that "where organic matter, such as plant remains, occurred the copper sulphide would be reduced to native copper." When present, organic matter undoubtedly produces these results, as shown by specimens obtained at Menlo Park and Glen Ridge, but the prevailing barrenness of the red Brunswick shales in this respect is well known. Were it otherwise the well nigh universal ferric coloring would present a chemical problem no less difficult than that of the copper ores themselves. Practically no organic matter occurs in the Somerville mine, replaced or otherwise, and the quantities found in connection with other copper ores of the State are wholly inadequate to account for more than a minute fraction of the total deposit.

(7) Weed's hypothesis fails to account in any manner for those ore-deposits that are in no way associated with trap rocks, as at New Brunswick, Menlo Park, Glen Ridge and Newtown. At all of these localities the underlying Palisades intrusive must be some thousands of feet below, and the extrusive sheet of First Mountain, if extended, would lie at a still greater distance above. The only known nearer trap masses in any of these

cases are thin dikes and equally thin sheets sometimes connected with them, and even these are seldom near.

A HYDROTHERMAL HYPOTHESIS.

The copper ores lie in a broad curved belt (See map, Pl. XXX) above the great intrusive sill of the Palisades and Rocky Hill and, with few small exceptions, below the extrusive trap sheet of First Mountain. As explained in the preceding pages, these deposits may be grouped into two general classes; namely, those with intrusive trap rocks and those without such associations. Of the latter, some are under or over the lowest extrusive sheet of the Watchungs, and others are out in the midst of the broad shale areas entirely apart from trap rocks of any kind. It is also clear, from the foregoing descriptions of the various deposits, that the ores of each of the leading types are remarkably uniform in character, the essential ore associated with intrusives being chalcocite, or glance, while apart from such association native copper chiefly occurs.

Origin of ores with intrusive traps.—The close association of these ores with intrusive sills, dikes and apophyses, and their position chiefly above such intrusives in the Griggstown (Rocky Hill) and Arlington mines leave little doubt that there is a genetic connection. That this is not merely a derivation through later alteration of the trap rocks by percolating waters and the simultaneous removal of the contained copper in solution is demonstrated by two conditions referred to above, namely, the position of the ores chiefly above instead of below the trap masses, and the quantity of ore as compared with the small amount of known trap rocks, especially at the Arlington mine.

There remains, therefore, the hypothesis of heated copper-bearing solutions, and possibly vapors, arising from the greater underlying mass of intrusives along the dikes and accompanying fissures, and depositing chalcocite in the immediate vicinity while still highly heated. Under the great pressure of overlying formations and the cooling influence of the surrounding strata, vapors probably could not exist more than a very short distance from the greater intrusive masses; and the chief effects may, therefore,

be safely ascribed to solutions, probably magmatic waters emanating directly from the molten lava.

At the Griggstown mine and vicinity the Rocky Hill intrusive sill, which lies but a few hundred feet below, sent up irregular dikes and finger-like apophyses into the overlying shales. Some of these now appear as the little rounded outcrops of trap that are scattered over this region. The shales are fissured but little, and this was undoubtedly confined, in the main, to the immediate vicinity of the intrusive. Shales more than a mile in thickness overlie this region, and many parts of these are highly charged with crystals of calcite. It is quite possible that some reaction of the solutions with this mineral have contributed to the deposition of the copper-bearing mineral, chalcocite.

At the Arlington mine the impregnated sandstone is penetrated by dikes and by thin sheets along the bedding planes. The solutions rose along the fissures of intrusion and their branchings in the adjacent sediments and penetrated the breccias and porous sandstones, impregnating them with ore. Doubtless waters also rose to higher horizons and escaped freely to the surface or formed ore deposits that have been subsequently removed by erosion. Similar conditions also exist at Flemington, where the ore-bearing solutions followed the intrusive dikes and accompanying fissures.

Origin of ores without associated intrusives.—It has been demonstrated[1] experimentally in the laboratory of the U. S. Geological Survey that a solution saturated with cuprous sulphate will deposit metallic copper on cooling, and that, therefore, a solution in which cupric sulphate has been partly reduced to cuprous sulphate by ferrous sulphate, pyrite, chalcocite, siderite, or silicates rich in ferrous iron, will deposit metallic copper if carried to a cooler region. It was also shown that if silver sulphate is present with the cuprous sulphate the silver will be deposited, on cooling, before the copper, and, hence, the two metals will appear in separate masses instead of combining to form an alloy.

[1] H. N. Stokes, Economic Geology, vol. 1, 1906, pp. 644–650.

In conformity with these results the Newark copper ores of the second type (that is, apart from intrusive trap) are readily conceived to be deposits from waters heated by and probably emanating from the great underlying intrusive trap sheet and its various branchings and ramifications through the sediments. Such waters must have permeated the strata over a wide area at the time of the intrusion of the traps and during the long period of slow cooling that followed, especially along the fissures and joint-cracks of the overlying shales, sandstones, and extrusive trap sheets. These waters were probably acid solutions of cuprous sulphate derived directly from the trap, and carrying a little silver and a trace of gold in solution. Their movements through the sediments were sufficiently obstructed in certain localities to permit a considerable accumulation of deposits through progressive cooling.

Probably these deposits were also augmented at times by chemical reactions between the solution and certain constituents of the inclosing rocks. As already described, the typical shales of this region are often more or less calcareous and contain minute crystals and small clusters of tabular calcite disseminated through them. Observations in many well-known mining regions have demonstrated the efficacy of this mineral as a precipitating agent in the formation of ore-deposits wherever the solutions are sufficiently retarded in their movements to permit the reactions to occur. At the same time the calcite would be thus removed in part, leaving the characteristic hollow, slit-like spaces more or less occupied by copper or copper-bearing minerals. In the same manner the ferric oxide coloring matter of the red shales has been leached out by the acid waters, leaving the grayish and whitish spots that mark the impregnated portions of the rock.

Such waters as escaped upward through the more extensive dislocations were intercepted in the vicinity of Somerville, Bound Brook and Plainfield by the extrusive trap sheet of First Mountain, and thus the layer of shale immediately beneath became charged with metallic copper. Some portions of the solution, however, found passage through the joints and fissures in the trap; and thus metallic copper is found in the midst of the trap

in the quarries at Chimney Rock, and small amounts of ore occur on top of the trap sheet of First Mountain and beneath the overlying shales of Washington Valley, at intervals from Pluckemin to Feltville.

At New Brunswick the underlying Palisades-Rocky Hill intrusive trap sill is probably as near as at the Arlington mine, and dikes that penetrate the shales to within a short distance of the city to the east, south and southwest, give evidence of widespread fissuring. Heavy ledges of sandstone underlie the shales at this place, as seen in the old quarries at the boat landing. The native copper and various secondary minerals derived from it, however, are in joints and fissures of the impervious overlying shales. Similar conditions seem to have prevailed at Newtown, where native silver is found associated with copper ores. The ores found at Glen Ridge are also doubtless of exactly the same character. The deposits in this case may have been fed by an extension of the same system of fissures through which the Arlington ores were brought up.

At Menlo Park the ores are confined to the breccia and walls of a well-marked heave-fault, through which the ore-bearing solutions must have come; and the abrupt termination of the fissure above makes it reasonably certain that they could only have come upward. At this and several other localities occasional bits of bituminous vegetable remains are found more or less infused with copper-bearing minerals, but not more so than much of the adjacent rock that is entirely barren of such materials; and in no case could the organic matter, even if all replaced, account for more than a very small amount of the ore actually deposited.

Summary of origin.—In all cases the Newark (Triassic) copper ores of New Jersey are attributable to the same source, namely, hot copper-bearing solutions, doubtless magmatic waters, deriving both their heat and their copper salts from the great underlying Palisades-Rocky Hill trap sill and its offshoots. The deposition of chalcocite in the heated portions near the intrusives and of native copper with a little chalcocite in the more remote, and, therefore, cold regions may, in both cases, have been chiefly

the result of cooling, supplemented perhaps in part by reactions with the widespread calcite of the sedimentary rocks. The conditions of extensive accumulation have been supplied by some relatively impervious member, a dense shale or a trap sheet, which has sufficiently impeded the movements of the uprising solutions to permit considerable cooling, and, therefore, extensive deposits, and also to allow time for possible reactions with the calcite of the sediments, and for leaching out the ferric coloring, in part, by the acid waters.

AGE OF THE COPPER ORES.

From the foregoing descriptions of the various ore deposits of this region it is clear that in many localities they are closely associated with the great Palisades-Rocky Hill instrusive trap sill, as at Griggstown, southwest of New Brunswick, and at Arlington. It is equally evident that the deposits along First Mountain, as at Somerville, Bound Brook and Plainfield, are of later origin than the overlying trap sheet, for they penetrate the trap itself, and small deposits of ore are found above the trap sheet and beneath the overlying shales.

The time of deposition of the ores is therefore correlated with the intrusion of the Palisades sill, which is regarded as their source, and subsequent to the extrusive flows of the Watchung Mountains. Other reasons for placing the date of the intrusive trap after the extrusives are discussed on pages 125–127. The ores were formed, therefore, very near the close of the Newark deposition in this region, and the great igneous intrusion may well have marked the beginning of those disturbances that led to the tilting and faulting of the whole series.

April 10, 1907.

Properties of Trap Rocks for Road Construction.

BY J. VOLNEY LEWIS.

Crushed trap rock for road construction was produced to the value of more than half a million dollars a year by the quarries of the State during the years 1903 and 1904, in addition to large amounts for railroad ballast and for concrete. The merits of this stone for the building of macadam roads have become generally known throughout the country, but it is not all equally adapted for all roads, as abundantly demonstrated by both experience and laboratory tests of the stone from the various quarries. Hence it was deemed advisable, in connection with the study of the geology and petrography of the trap rocks, to collect specimens from the more accessible localities and submit these to the Office of Public Roads, Department of Agriculture, Washington, D. C., for systematic examination of their properties for road construction.

The accompanying table and diagram represent the results of these tests, including some half a dozen samples that had been previously submitted by others. In the column designated "French coefficient of wear," the higher the number the more durable the rock; higher values also indicate superior "Hardness" and "Toughness" in the next two columns. Under "Cementing value" the higher numbers show greater binding power of the finely powdered material. In further explanation of these properties as affecting the adaptability of a stone for road building, the following is quoted from Mr. L. W. Page, Director of the Office of Public Roads:[1]

[1] Yearbook of the U. S. Department of Agriculture for 1900, p. 351.

"By hardness is meant the power possessed by a rock to resist the wearing action caused by the abrasion of wheels and horses' feet. Toughness, as understood by road builders, is the adhesion between the crystals and fine particles of a rock, which gives it power to resist fracture when subjected to the blows of traffic. This important property, while distinct from hardness, is yet intimately associated with it, and can, in a measure, make up for a deficiency in hardness. Hardness, for instance, would be the resistance offered by a rock to the grinding of an emery wheel; toughness the resistance to fracture when struck with a hammer.

"Cementing or binding power is the property possessed by the dust of a rock to act after wetting as a cement to the coarser fragments composing the road, binding them together and forming a smooth, impervious shell over the surface. Such a shell, formed by a rock of high cementing value, protects the underlying material from wear and acts as a cushion to the blows from horses' feet, and at the same time resists the waste of material caused by wind and rain, and preserves the foundation by shedding the surface water. Binding power is thus probably the most important property to be sought for in a road-building rock, as its presence is always necessary for the best results.

"The hardness and toughness of the binder surface more than of the rock itself represents the hardness and toughness of the road, for if the weight of traffic is sufficient to destroy the bond of cementation of the surface, the stones below are soon loosened and forced out of place. When there is an absence of binding material, which often occurs when the rock is too hard for the traffic to which it is subjected, the road soon loosens or ravels.

"Experience shows that a rock possessing all three of the properties mentioned in a high degree does not under all conditions make a good road material; on the contrary, under certain conditions, it may be altogether unsuitable. As an illustration of this, if a country road or a city parkway, where only a light traffic prevails, were built of a very hard and tough rock with a high cementing value, neither the best, nor, if a softer rock were available, would the cheapest results be obtained. Such a rock would so effectively resist the wear of a light traffic that the amount of fine dust worn off would be carried away by wind and rain faster than it would be supplied by wear. Consequently, the binder supplied by wear would be insufficient, and if not supplied from some other source the road would soon go to pieces. The first cost of such a rock would in most instances be greater than that of a softer one, and the necessary repairs resulting from its use would also be very expensive. * * *

"The degree to which a rock absorbs water may also be important, for in cold climates this to some extent determines the liability of a rock to fracture by freezing. It is not so important, however, as the absorptive power of the road itself, for if the road holds much water the destruction wrought by frost is very great. This trouble is generally due to faulty construction rather than to material. The density or weight of a rock is also considered of importance, as the heavier the rock the better it stays in place and the better it resists the action of wind and rain."

THE SELECTION OF A STONE FOR MACADAM ROADS.

As stated above, a stone of the greatest hardness, toughness, and cementing power does not make the best road under all circumstances; in fact such material would give the best results only under the most severe conditions of heavy traffic. It is equally true that a stone of the same general kind or class does not always possess these properties in the same degree. The trap rocks, for instance, vary greatly in their texture, chemical composition, and degree of alteration, and these variations affect to a marked degree the properties of the stone for road construction.

The trap rock produced by the various quarries varies from exceedingly dense, fine-grained and even partly glassy condition to a coarse-grained, granitic texture, in which the individual minerals are developed in grains of one-fourth of an inch or more in diameter. Under the microscope the "habit" of the mineral particles is seen also to vary greatly; in some cases they are of about equal dimensions in every direction, tending toward a rounded form, in others they are greatly elongated, lath-shaped and rod-shaped forms. Other things being equal, fine-grained varieties and those composed of interlocking, elongated minerals possess a higher degree of toughness.

Variations in chemical composition are accompanied chiefly by corresponding variations in the proportions of the minerals pyroxene and feldspar (labradorite), the two principal constituents of the trap rocks of this region. Of these the former possesses the greater toughness and the latter the greater hardness. In some of the more basic varieties olivine (chrysolite) may constitute as much as 10 per cent. of the rock. This mineral is somewhat harder even than the feldspar, but it is usually more or less altered into serpentine, which is considerably softer. The pyroxene is also subject to extensive alteration into greenish chloritic minerals, which are also much softer than the original mineral. The feldspar is somewhat less subject to extensive alteration, but is often partly changed into a soft white powdery kaolin.

Thus it will be readily understood that while some trap rocks are very hard and tough and suited only for heavy-traffic roads, there are others that are not suited to such severe conditions and are better adapted to suburban streets, park ways, and country roads. Too often, however, the selection of the material for road building is made solely with a view to convenience or cheapness of the stone, with the result that an inferior road is constructed and the economy in first cost is more than counterbalanced by the expense of maintenance. Such initial carelessness may result in the selection of a stone that is too hard and tough for the traffic to which it is subjected or one that is too soft and brittle.

"If the surface of a macadam road continues to be too muddy or dusty after the necessary drainage precautions have been followed, then the rock of which it is constructed lacks sufficient hardness or toughness to meet the traffic to which it is subjected. If, on the contrary, the fine binding material of the surface is carried off by wind and rain and is not replaced by wear of the coarser fragments, the surface stones will soon loosen and allow water to make its way freely to the foundation and bring about the destruction of the road. Such conditions are brought about by an excess of hardness or toughness of the rock for the traffic. Under all conditions a rock of high cementing value is desirable; for, other things being equal, such a rock better resists the wear of traffic and the action of wind and rain."

The different classes of traffic have been divided into five groups, according to volume and character, as follows:

1. City traffic, such as exists on the business streets of large cities. The conditions are too severe for any macadam, and more resistant forms of pavement must be used.

2. Urban traffic, that of the less severe city conditions, but subjected to heavy traffic and requiring the hardest and toughest macadam.

3. Suburban traffic, that of suburbs of larger cities and main streets of country towns, requiring a macadam of high toughness but somewhat less hardness than the preceding.

4. Highway traffic, such as exists on the principal country roads. A rock of medium hardness and toughness is best.

5. Country-road traffic, that of the less frequented country roads. For this it is best to use a comparatively soft rock of medium toughness.

In the diagram, figure 9, the samples are arranged according to the French coefficient of wear, beginning with the greatest

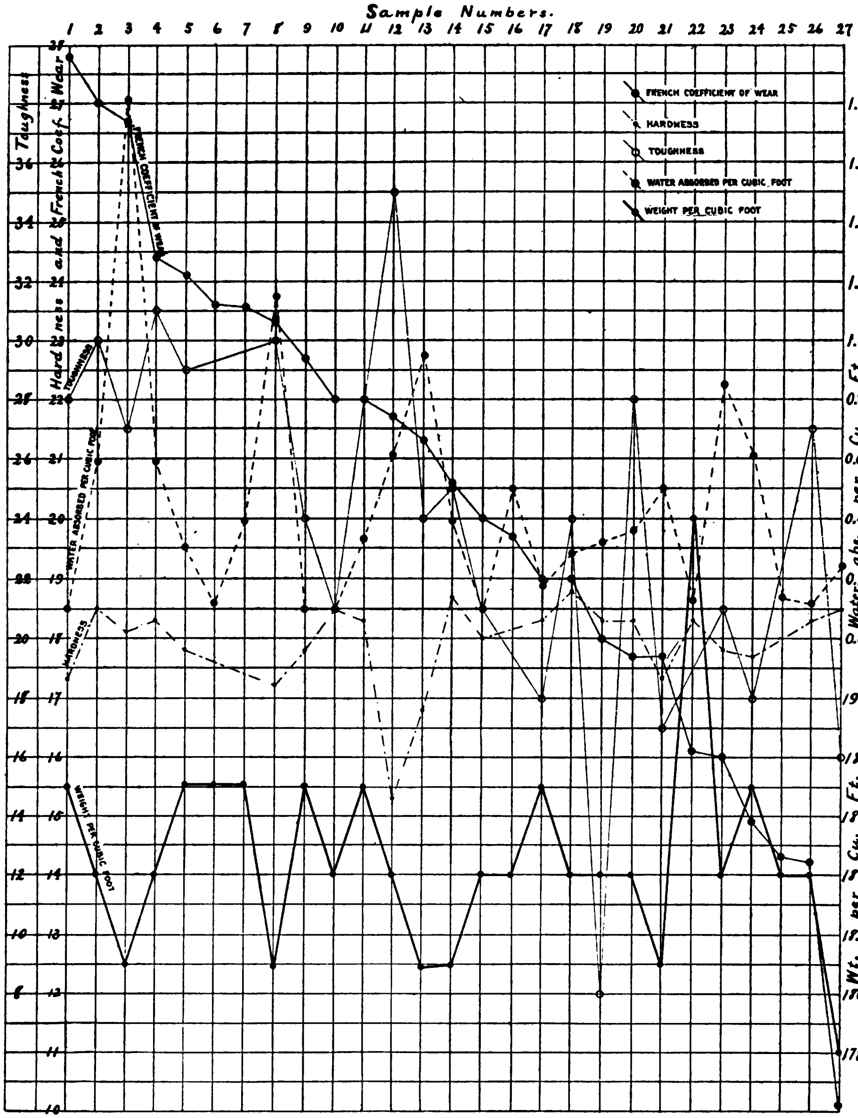

Fig. 9.
Diagram showing tests on trap rock as road metal.

and decreasing toward the right, while hardness, toughness, and other properties vary irregularly. Therefore those stones that

fall on the left-hand side and toward the middle of the diagram and show at the same time great hardness and toughness are best adapted to urban and other very heavy-traffic uses; while those in the middle of the diagram with moderate hardness and toughness, and toward the left with lower or toward the right with higher values of these properties, are suitable for suburban and heavy-traffic highway purposes. Those toward the right-hand side with medium and further to the left with low hardness and toughness are adapted to lighter suburban and ordinary highway traffic conditions. Even the softest and most brittle material in the list is too resistant for the best results on the less frequented country roads, unless combined with softer materials to furnish the necessary fine powder for cementing.

It should be a matter of interest to all who are in any way responsible for road construction or maintenance, as well as to owners of quarries supplying road materials, to know that the U. S. Department of Agriculture has a fully equipped road-material laboratory, where any person residing in the United States may have tests made free of charge by applying for instructions to the Office of Public Roads, Dept. Agriculture, Washington, D. C. Acknowledgements are due to Mr. L. W. Page, director of this office, for the valuable data presented in the accompanying table and for many courtesies extended during the collection and testing of the materials.

April 10, 1907.

RESULTS OF TESTS OF NEW JERSEY TRAP ROCKS

Made by the Office of Public Roads, U. S. Dept. of Agriculture, Washington, D. C.

	Specific gravity.	Weight per cu. ft. (Lbs.)	Water absorbed per cu. ft.	Per cent. of wear.	French coefficient of wear.	Hardness.	Toughness.	Cementing value.	Designation on Fig. 9.	Dept. Agr. Lab. No.
BERGEN COUNTY.										
Shadyside Quarries,	3.0	184.0	0.50	2.0	19.7	.....	.....	38 dry; 211 wet,	(16)	566
ESSEX COUNTY.										
Great Notch, Francisco Bros., Quarry No. 1,	2.9	180.9	0.95	1.9	21.3	16.8	24	12 dry; 125 wet,	(13)	986
Great Notch, Francisco Bros., Quarry No. 2,	2.9	184.0	0.61	1.8	21.7	15.3	35	51 dry; 283 wet,	(12)	987
Milburn, C. A. Lighthipe & Son,	2.95	184.0	0.10	2.0	20.0	18.0	21	Excellent,	(15)	1718
Upper Montclair, Osborne & Marsellis,	2.99	187.1	0.30	1.7	24.1	17.8	29	21 dry,	(5)	988
Verona, F. J. Marley,	2.90	181.0	0.50	2.3	17.7	17.3	17	Excellent,	(21)	1727
West Orange, John O'Rourke,	2.95	184.0	0.10	1.8	22.0	18.5	21	Excellent,	(10)	1721
West Orange, "black trap," Geo. Spottiswoode & Co.,	3.00	187.0	0.10	1.8	22.7	17.8	24	Excellent,	(9)	1753
West Orange, "gray trap," Geo. Spottiswoode & Co.,	3.00	187.0	0.10	1.4	27.8	17.3	28	Good,	(1)	1754
West Orange, "blue trap," Geo. Spottiswoode & Co.,	2.95	184.0	0.36	2.3	17.7	18.3	28	Excellent,	(20)	1755
HUDSON COUNTY.										
Jersey City, O'Neill & Hopkins,	3.15	196.0	0.13	2.5	16.1	18.3	19	Good,	(22)	1773
Snake Hill, Prison Quarry,	2.95	184.0	0.12	2.8	14.2	18.3	27	Excellent,	(26)	1751
Snake Hill, N. J. Trap Rock Co.,	3.00	187.0	0.18	2.1	19.0	18.3	18	Excellent,	(17)	1756
HUNTERDON COUNTY.										
Lambertville,	2.90	184.0	0.14	2.8	14.3	.....	.....	131 wet,	(25)	387
MORRIS COUNTY.										
Millington, Morris Co. Crushed Stone Co.,	3.00	187.0	0.61	2.7	14.9	17.7	18	500 wet,	(24)	1708
Mountain View, Helmer Hosier,	2.95	184.0	0.85	2.5	16.0	17.8	21	Good,	(23)	1730
PASSAIC COUNTY.										
Albion Place, W. A. Ferguson,	2.95	184.0	0.59	1.5	27.0	18.5	30	Good,	(2)	1717
Montclair Heights, Wright & Lindsley,	2.95	184.0	0.28	2.1	19.0	18.8	24	Excellent,	(18)	1713
Paterson, Paterson Crushed Stone Co.,	2.90	181.0	0.39	1.9	20.6	18.7	25	Excellent,	(14)	1716
Paterson, McKiernan & Bergin,	2.95	184.0	0.59	1.6	24.4	18.3	31	Excellent,	(4)	1731

RESULTS OF TESTS OF NEW JERSEY TRAP ROCKS—Continued.

	Specific gravity.	Weight per cu. ft. (Lbs.)	Water absorbed per cu. ft.	Per cent. of wear.	French coefficient of wear.	Hardness.	Toughness.	Cementing value.	Designation on Fig. 9.	Dept. Agr. Lab. No.
SOMERSET COUNTY.										
Bernardsville, Somerset Stone Crushing Co.,	2.85	178.0	0.24	4.0	10.1	18.5	16	Excellent,	(27)	1719
Bound Brook, Wm. Haelig,	2.98	187.1	0.12	1.69	23.61	.....	.....	72 dry,	(6)	357
Bound Brook, Bound Brook Crushed Stone Co.,	2.90	181.0	1.81	1.5	26.7	18.1	27	96 dry; 298 wet,	(3)	1619
Warrenville, E. E. Cooper,	3.00	187.0	0.33	1.8	22.0	18.3	28	70 dry,	(11)	1706
UNION COUNTY.										
New Providence, A. A. Potter,	2.98	187.1	0.39	1.7	23.58	.....	.....	19 dry,	(7)	350
Springfield, Stewart Hartshorn,	2.90	180.9	1.15	1.7	23.3	17.2	30	22 dry; 174 wet,	(8)	912
Summit, Commonwealth Quarry Co.,	2.95	184.0	0.32	2.2	18.0	18.3	8	225 wet,	(19)	1707
MAXIMUM AND MINIMUM RESULTS ON 103 SAMPLES OF TRAP (DIABASE).										
Minima,	2.60	162.0	0.03	1.2	6.4	13.0	4	2 dry; 7 wet,		
Maxima,	3.20	200.0	2.73	6.3	34.5	19.3	54	301 dry; 500 wet,		
Averages,	2.95	184.0	.....	.....	.....	.....	.....			

PART IV.

Notes on the Mining Industry.

By HENRY B. KÜMMEL.

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Notes on the Mining Industry.

BY HENRY B. KÜMMEL.

THE IRON MINES.

During 1906 the following iron mines were producers: the Washington and Ahles, at Oxford; the Hurd, Richard and Hoff, at Wharton; the Mount Hope mines, at Mount Hope; the Hude, at Stanhope; the Andover, DeCamp, Upper Wood and Wharton, at Hibernia; the Dickerson, at Ferro Mont; and the Peters, at Ringwood. Development has been carried forward at the Teabo and Scrub Oak or Dell, but these are not yet to be classed as producers.

The total product during the year was 542,488 long tons, a gain over the figures of 1905. The steady increase since 1897 in production as shown by the figures on page 180 are certainly encouraging. The value of the ore at the mines is estimated at $1,560,000.

At the Ahles mine, Oxford, of the Basic Iron Ore Company, mining has been carried on from No. 1 and No. 3 shafts and Slope No. 4 has been sunk so that it is expected to reach ore early in 1907. As has been mentioned in previous reports, the ore from this mine is a mixture of magnetite and limonite, carrying about 4 per cent. of manganese. With the completion of the new slope, it will be possible to increase very largely the annual output. The ore is mined by the caving system.

The Empire Steel and Iron Company, of Catasauqua, Pa., are operating only the Washington mine at Oxford, and have done considerable development work in that vicinity, and from present indications the output of this mine will be largely increased and its grade of ore raised when contemplated improvements are

completed. At Mount Hope a new shaft, the Leonard, has been opened to mine ore from the Side Hill vein and the Findley vein, and it is planned to sink a new shaft on the Brannin vein. The Elizabeth mine has been a producer during the year.

The Musconetcong Iron Company, at Stanhope, has continued to operate the Hude mine at Stanhope, and also the Dickerson mine at Ferro Mont, but both mines were only small producers.

The Richard mine, owned by the Thomas Iron Company of Easton, has continued to be a large producer and has maintained the high record of tonnage of the last few years.

At the Hoff mine, at Wharton, which was reopened in 1905 by the Hoff Mining and Realty Improvement Co. of Rockaway, N. J., the raising of ore has continued and a new tunnel has been started on another vein about half a mile from the old mine.

All the Joseph Wharton properties have been the scene of activity and development. The improvements at the Hurd mine at Wharton, commenced in 1905, were carried forward with the result that that mine is now a larger producer than for many years previous. At the Hibernia mines a new ore body has been located a few hundred feet northwest of the one heretofore worked. At a depth of 75 feet on the dip, lean ore containing about 30 to 32 per cent. of iron was crosscut for a distance of 35 feet. Further exploratory work upon this body will be made this year. The Scrub Oak or Dell mine, northwest of Mine Hill, has been pumped out and explored and a new shaft is being sunk to a large body of low-grade ore. At the Teabo mine a crosscut at the 800-foot level of the new shaft struck a 2-foot vein of rich magnetite at a distance of 27 feet in the hanging wall, and a thicker ore body on the footwall side at a distance of about 40 feet from the shaft. The shaft was then sunk 40 feet and crosscutting was again commenced to these ore bodies.

THE ZINC MINES.

The New Jersey Zinc Company's mines at Franklin have shown a large increase in production over that of 1905. During the first part of the year most of the ore obtained came from the drives extended along the various levels, as in former years. In

the latter part of the year, however, considerable ore was broken from the open cut at the extreme south end of the ore body. Cableways, with the necessary bins, were erected, and these are expected to handle the ore which lies south of "The Dike."

A new shaft has been started, which, going down at an angle of 47½° in the footwall rock, will command the full depth of the deposit and deliver the ore directly into the mill. Very considerable extensions and additions to the plant are contemplated.

The company reports a total of 361,330 tons of ore mined during 1906.

THE LIMESTONE INDUSTRY.

In the Annual Report for 1905, the chemical composition of the white limestone of Sussex and Warren counties was discussed at some length, and a map published showing the distribution of the most important areas. The demand for this rock has so increased that the Survey proposes hereafter to compile annually statistics and a brief summary of the industry.

Quarries.—During 1906, the following firms were quarrying the crystalline limestone:

	Office.	*No. of Quarries.*	*Location.*	*Chief Use.*
Bethlehem Steel Co.	South Bethlehem	1	McAfee	Flux
Bigelow & Swain	Newark	1	Ogdensburg,	Portland cement and flux
Crestmore Stone Co.	Dover	1	Pinkneyville,	Portland cement and flux
Edison Portland Cement Co.	Stewartsville	1*	"	Portland cement
N. H. Hunt	Newton	1	"	Flux and cement
New Jersey Lime Co.	McAfee	3	Hamburg and McAfee	Lime
B. Nicoll & Co.	New York	3	Franklin Furnace	Flux
The Windsor Lime Co.	Newark	1	Hamburg	Lime

Product.—The total production during the year, as compiled from reports furnished the State Geologist by the producers, was 459,927 tons. These figures are only approximately correct,

* In November the Crestmore Stone Company's quarry was leased by the Portland Cement Company.

inasmuch as the returns from at least three sources were given in round numbers to the nearest thousand, and in one or two other instances only to the nearest hundred tons. However, the figures cannot be far from the truth, and can be accepted as substantially correct, the probable error being less than one-half of one per cent.

Uses.—It is not possible to determine from the returns the respective amounts used for various purposes. Apparently by far the largest part is used as a flux, both in blast furnaces and open-hearth steel furnaces. The demand for Portland Cement is also large, and less than 15 per cent. is burned for lime.

New quarries.—The quarry of Bigelow & Swain was opened in July, so that the output there was for but a part of the year. According to 16 analyses furnished the Survey by this firm, the rock of their quarry, omitting one special sample, has the following constitution:

	Maximum.	*Minimum.*
Silica,	0.82	0.32
Iron Oxide and Alumina,	0.90	0.20
Carbonate of Lime,	97.31	94.23
Carbonate of Magnesia,	4.57	1.43

One hundred and three carloads of rock shipped the Thomas Iron Company were reported to average only 0.55 per cent silica. These facts confirm the conclusions published in the Annual Report for 1905, that much of the white limestone is a very pure non-dolomitic limestone, and also indicate that the fresh rock obtainable in a quarry may be purer than indicated by analyses of samples taken from surface ledges.[1]

March 15, 1907.

[1] Compare Analysis No. 21, p. 184, Annual Report of the State Geologist, 1905.

Mineral Statistics.

For the Year 1906.

IRON ORE.

The total production of the mines, as reported by the several mining companies, was 542,488 tons.

The table of statistics is reprinted, with the total amount for 1903 added.

TABLE OF STATISTICS.

Year.	*Iron Ore.*	*Authority.*
1790	10,000 tons	Morse's estimate.
1830	20,000 tons	Gordon's Gazetteer.
1855	100,000 tons	Dr. Kitchell's estimate.
1860	164,900 tons	U. S. census.
1864	226,000 tons	Annual Report State Geologist.
1867	275,067 tons	" " "
1870	362,636 tons	U. S. census.
1871	450,000 tons	Annual Report State Geologist.
1872	600,000 tons	" " "
1873	665,000 tons	" " "
1874	525,000 tons	" " "
1875	390,000 tons	" " "
1876	285,000 tons	" " "
1877	315,000 tons*	" " "
1878	409,674 tons*	" " "
1879	488,028 tons	" " "
1880	745,000 tons	" " "
1881	737,052 tons	" " "
1882	932,762 tons	" " "
1883	521,416 tons	" " "
1884	393,710 tons	" " "
1885	330,000 tons	" " "
1886	500,501 tons	" " "
1887	547,889 tons	" " "
1888	447,738 tons	" " "

* From statistics collected later.

Year.	Iron Ore.	Authority.
1889	482,109 tons	Annual Report State Geologist.
1890	552,996 tons	" " "
1891	551,358 tons	" " "
1892	465,455 tons	" " "
1893	356,150 tons	" " "
1894	277,483 tons	" " "
1895	282,433 tons	" " "
1896	264,999 tons	" " "
1897	257,235 tons	" " "
1898	275,378 tons	" " "
1899	300,757 tons	" " "
1900	342,390 tons*	" " "
1901	401,151 tons	" " "
1902	443,728 tons	" " "
1903	484,796 tons*	" " "
1904	499,952 tons	" " "
1905	500,541 tons	" " "
1906	542,488 tons	" " "

ZINC ORE.

The production of the New Jersey Zinc Company's mines is reported by the company to be 361,330 gross tons of zinc and franklinite ore. It was chiefly separated at the company's mills. This report shows a gain in production over 1905 of 38,268 tons.

The statistics for a period of years are reprinted from the last annual report.

ZINC ORE.

Year.	Zinc Ore.	Authority.
1868	25,000 tons†	Annual Report State Geologist.
1871	22,000 tons†	" " "
1873	17,500 tons	" " "
1874	13,500 tons	" " "
1878	14,467 tons	" " "
1879	21,937 tons	" " "
1880	28,311 tons	" " "
1881	49,178 tons	" " "
1882	40,138 tons	" " "
1883	56,085 tons	" " "

* The figures, 407,596 tons, given in the report for 1900, included 75,206 tons of crude material which should have been reduced to its equivalent in concentrates. The figures for 1903, given in the report for that year, were incorrect.

† Estimated for 1868 and 1871. Statistics for 1873–1890, inclusive, are for shipments by railway companies. The later reports are from zinc-mining companies.

Year.	*Zinc Ore.*	*Authority.*
1884	40,094 tons	Annual Report State Geologist.
1885	38,526 tons	" " "
1886	43,877 tons	" " "
1887	50,220 tons	" " "
1888	46,377 tons	" " "
1889	56,154 tons	" " "
1890	49,618 tons	" " "
1891	76,032 tons	" " "
1892	77,298 tons	" " "
1893	55,852 tons	" " "
1894	59,382 tons	" " "
1895*		
1896	78,080 tons	" " "
1897	76,973 tons	" " "
1898	99,419 tons	" " "
1899	154,447 tons	" " "
1900	194,881 tons	" " "
1901	191,221 tons	" " "
1902	209,386 tons	" " "
1903	279,419 tons	" " "
1904	250,025 tons	" " "
1905	323,062 tons	" " "
1906	361,330 tons	" " "

* No statistics were published in the Annual Report for 1895.

Publications.

It is the wish of the Board of Managers to complete, so far as possible, incomplete sets of the publications of the Survey, chiefly files of the Annual Reports in public libraries, and librarians are urged to correspond with the State Geologist concerning this matter.

The Annual Reports of the State Geologist are printed by order of the Legislature as a part of the legislative documents. They are distributed by the State Geologist to libraries and public institutions, and, so far as possible, to any who may be interested in the subjects of which they treat.

Six volumes of the Final Report series have been issued. Volume I, published in 1888, has been very scarce for several years, but all the valuable tables were reprinted in an appendix of Volume IV, of which a few copies still remain, although the supply of this volume is so far reduced that indiscriminate requests cannot be granted.

The appended list makes brief mention of all the publications of the present Survey since its inception in 1864, with a statement of the editions now out of print. The reports of the Survey are distributed without further expense than that of transportation. Single reports can usually be sent more cheaply by *mail* than otherwise, and requests should be accompanied by the proper postage as indicated in the list. Otherwise they are sent *express collect. When the stock on hand of any report is reduced to 200 copies, the remaining volumes are withdrawn from free distribution and are sold at cost price.*

The maps are distributed only by sale, at a price, 25 cents per sheet, to cover cost of paper, printing and transportation. In order to secure prompt attention, requests for both reports and maps should be addressed simply "State Geologist," Trenton, N. J.

CATALOGUE OF PUBLICATIONS.

GEOLOGY OF NEW JERSEY. Newark, 1868, 8vo., xxiv + 899 pp. Out of print.

PORTFOLIO OF MAPS accompanying the same, as follows:

1. Azoic and paleozoic formations, including the iron-ore and limestone districts; colored. Scale, 2 miles to an inch.

2. Triassic formation, including the red sandstone and trap-rocks of Central New Jersey; colored. Scale, 2 miles to an inch.

3. Cretaceous formation, including the greensand-marl beds; colored. Scale, 2 miles to an inch.

4. Tertiary and recent formations of Southern New Jersey; colored. Scale, 2 miles to an inch.

5. Map of a group of iron mines in Morris county; printed in two colors. Scale, 3 inches to 1 mile.

6. Map of the Ringwood iron mines; printed in two colors. Scale, 8 inches to 1 mile.

7. Map of Oxford Furnace iron-ore veins; colored. Scale, 8 inches to 1 mile.

8. Map of the zinc mines, Sussex county; colored. Scale, 8 inches to 1 mile.

A few copies can be distributed at $2.00 per set.

REPORT ON THE CLAY DEPOSITS of Woodbridge, South Amboy and other places in New Jersey, together with their uses for firebrick, pottery, etc. Trenton, 1878, 8vo., viii + 381 pp., with map. Out of print.

A PRELIMINARY CATALOGUE of the Flora of New Jersey, compiled by N. L. Britton, Ph.D. New Brunswick, 1881, 8vo., xi + 233 pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. I. Topography. Magnetism. Climate. Trenton, 1888, 8vo., xi + 439 pp. Out of print.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part I. Mineralogy. Botany. Trenton, 1889, 8vo., x + 642 pp. Unbound copies, postage 22 cents. Bound copies, $1.50.

FINAL REPORT OF THE STATE GEOLOGIST. Vol. II. Part II. Zoology. Trenton. 1890, 8vo., x + 824 pp. (Postage, 30 cents.)

REPORT ON WATER-SUPPLY. Vol. III of the Final Reports of the State Geologist. Trenton, 1894, 8vo., xvi + 352 and 96 pp. (Postage, 21 cents.)

REPORT ON THE PHYSICAL GEOGRAPHY of New Jersey. Vol. IV of the Final Reports of the State Geologist. Trenton, 1898, 8vo., xvi + 170 + 200 pp. Unbound copies, postage 24 cents; cloth bound, $1.35, with photo-relief map of State, $2.85. Map separate, $1.50. Scarce.

REPORT ON THE GLACIAL GEOLOGY of New Jersey. Vol. V of the Final Reports of the State Geologist. Trenton, 1902, 8vo., xxvii + 802 pp. (Sent by express, 35 cents if prepaid, or charges collect.)

REPORT ON CLAYS AND CLAY INDUSTRY of New Jersey. Vol. VI. of the Final Reports of the State Geologist. Trenton, 1904, 8vo., xxviii + 548 pp. (Sent by express, 30 cents if prepaid, or charges collect.)

BRACHIOPODA AND LAMELLIBANCHIATA of the Raritan Clays and Greensand Marls of New Jersey. Trenton, 1886, quarto, pp. 338, plates XXXV and Map. (Paleontology, Vol. I.) (By express.)

GASTEROPODA AND CEPHALOPODA of the Raritan Clays and Greensand Marls of New Jersey. Trenton, 1892, quarto, pp. 402, plates L. (Paleontology, Vol. II.) (By express.)

PALEOZOIC PALEONTOLOGY. Trenton, 1903, 8 vo., xii + 462 pp., plates LIII. (Paleontology, Vol. III.) (Postage, 20 cents.)

ATLAS OF NEW JERSEY. The complete work is made up of twenty sheets, each about 27 by 37 inches, including margin. Seventeen sheets are on a scale of 1 inch per mile and three on a scale of 5 miles per inch. It is the purpose of the Survey gradually to replace Sheets 1-17 by a new series of maps, upon the same scale, but somewhat differently arranged so as not to overlap. The new sheets will be numbered from 21-37, and will be subject to extensive revision before publication. These sheets will each cover the same territory as eight of the large maps, on a scale of 2,000 feet per inch. Nos. 1, 2, 4, 5, 7, 8, 11, 12, 13 and 17 have already been replaced as explained below.

No. 9. Monmouth Shore, with the interior from Metuchen to Lakewood.

No. 10. Vicinity of Salem, from Swedesboro and Bridgeton westward to the Delaware.

No. 14. Vicinity of Bridgeton, from Allowaystown and Vineland southward to the Delaware bay shore.

No. 18. New Jersey State Map. Scale, 5 miles to the inch. Geographic.[1]

No. 19. New Jersey Relief Map. Scale, 5 miles to the inch. Hypsometric.

No. 20. New Jersey Geological Map. Scale, 5 miles to the inch. (Out of print.)

No. 21. Northern Warren and Western Sussex counties. Replaces Sheet 1.

No. 22 Eastern Sussex and Western Passaic counties. Replaces Sheet 4.

No. 23. Northern Bergen and Eastern Passaic counties, to West Point, New York. Replaces northern part of Sheet 7.

No. 24. Southern Warren, Northern Hunterdon and Western Morris counties. Replaces Sheet 2.

No. 26. Vicinity of Newark and Jersey City—Paterson to Perth Amboy. Replaces in part Sheet 7.

No. 27. Vicinity of Trenton—Raven Rock to Palmyra, with inset, Trenton to Princeton. Replaces Sheet 5.

No. 28. Trenton and Eastward—Trenton to Sayreville. Replaces Sheet 8.

No. 31. Vicinity of Camden, to Mount Holly, Hammonton and Elmer. Replaces Sheet 11.

No. 32. Part of Burlington and Ocean counties, from Pemberton and Whitings to Egg Harbor City and Tuckerton. Replaces Sheet 12.

No. 33. Southern Ocean County, Tucketron to Tom's River and Chadwicks. Replaces Sheet 13.

No. 35. Vicinity of Millville, from Vineland to Port Norris and Cape May Court House. (In preparation.)

No. 36. Parts of Atlantic and Cape May Counties. Egg Harbor City to Townsend's Inlet. (In preparation.)

No. 37. Cape May.—Cape May City to Ocean City and Mauricetown.

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[1] At the date of preparing this report this sheet is out of print. A new map of the State, showing the municipalities in colors, will be issued about April 15th, 1907.

Other sheets of the new series, Nos. 21-37, will be printed from time to time, as the older sheets become out of print. All the maps are sold at the uniform price of twenty-five cents per sheet, either singly or in lots. Since the Survey cannot open small accounts, and the charge is merely nominal, remittance should be made with the order. Order by *number* of the State Geologist, Trenton, N. J.

TOPOGRAPHIC MAPS, NEW SERIES.

These maps are the result of recent revision of the earlier surveys, and contain practically all of the features of the one-inch scale maps, with much new material. They are published on a scale of 2,000 feet to an inch, and the sheets measure 26 by 34 inches. The Hackensack, Paterson, Boonton, Dover, Jersey City, Newark, Morristown, Chester, New York Bay, Elizabeth, Plainfield, Pluckemin, Amboy, New Brunswick, Somerville, Navesink, Long Branch, Shark River, Trenton Camden, Mt. Holly, Woodbury, Taunton Sheets and Atlantic City have been published and are now on sale. The price is twenty-five cents per sheet, *payable in advance*. Order by *name* any of the sheets above indicated as ready, of The State Geologist, Trenton, New Jersey.

ANNUAL REPORTS.

REPORT OF PROFESSOR GEORGE H. COOK upon the Geological Survey of New Jersey and its progress during the year 1863. Trenton, 1864, 8vo., 13 pp. Out of print.

THE ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to his Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1864. Trenton, 1865, 8vo., 24 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, to his Excellency Joel Parker, President of the Board of Managers of the Geological Survey of New Jersey, for the year 1865. Trenton, 1866, 8vo., 12 pp. Out of print.

ANNUAL REPORT of Prof. Geo. H. Cook, State Geologist, on the Geological Survey of New Jersey, for the year 1866. Trenton, 1867, 8vo., 28 pp. Out of print.

REPORT OF THE STATE GEOLOGIST, Prof. Geo. H. Cook, for the year of 1867. Trenton, 1868, 8vo., 28 pp. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1869. Trenton, 1870, 8vo., 57 pp., with maps. Out of print.

ANNUAL REPORT of the State Geologist of New Jersey for 1870. New Brunswick, 1871, 8vo., 75 pp., with maps. Very scarce.

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